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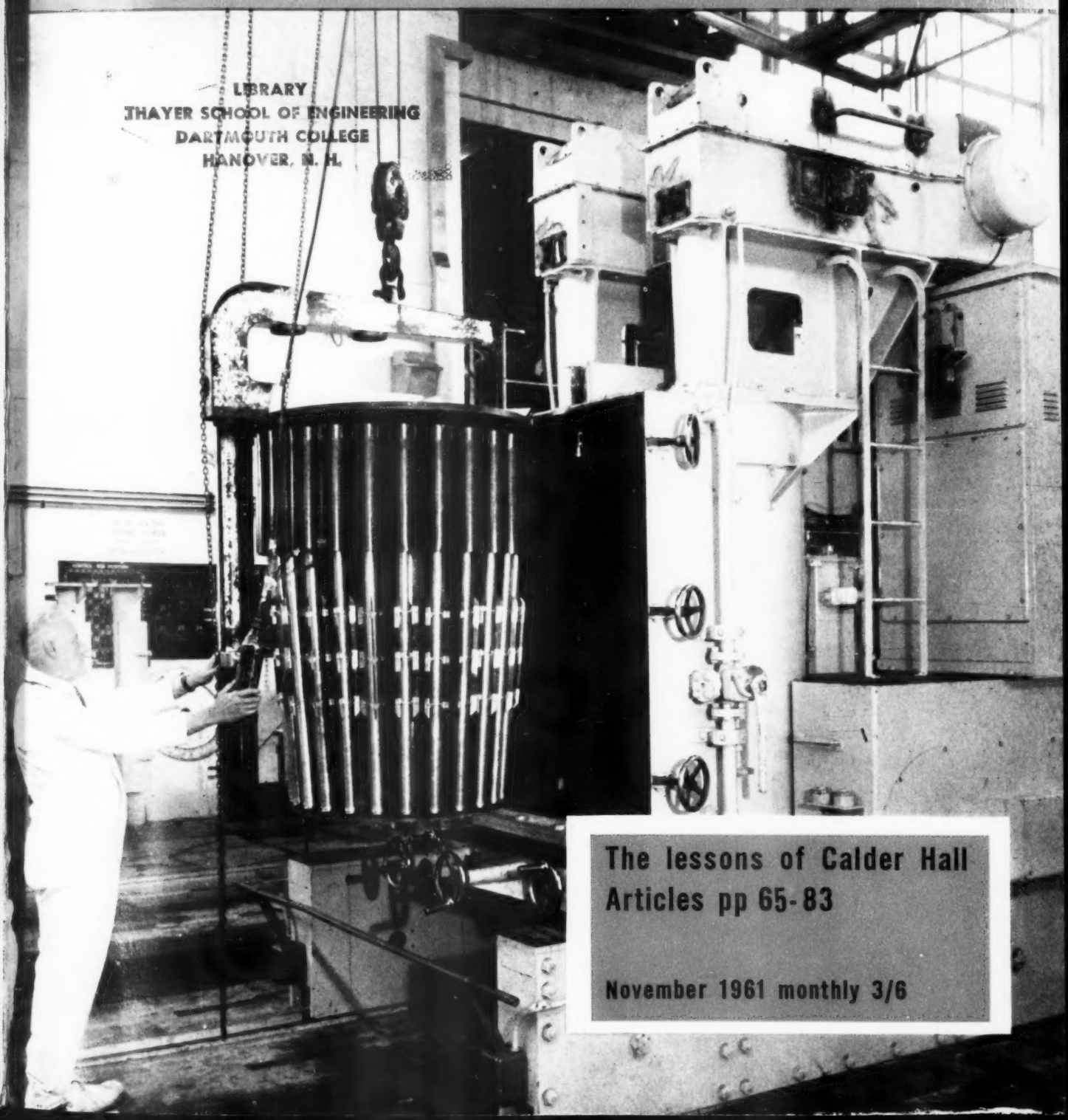

The lessons of Calder Hall
Articles pp 65-83

November 1961 monthly 3/6

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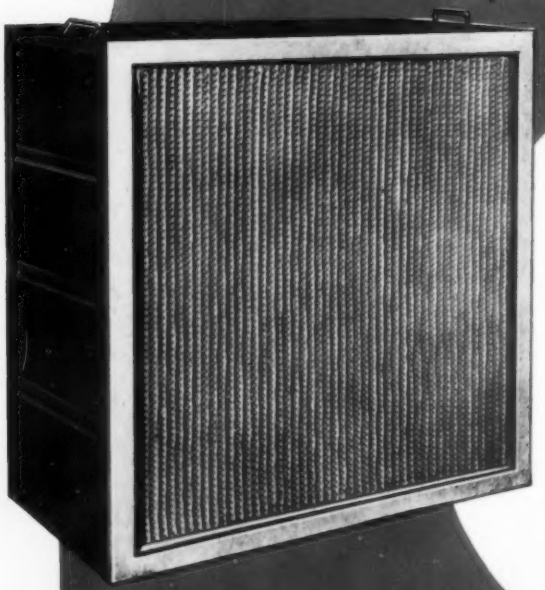

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COVER PICTURE

Placing a charge basket containing 24 new fuel elements into one of the Calder Hall charge machines

Nuclear Power

REACTORS · MATERIALS · INSTRUMENTATION · PROCESSES · IRRADIATION

SPECIAL FEATURES

THE LESSONS OF CALDER HALL

Twenty five reactor years operating experience at Calder and Chapelcross, with 85% plant utilization and at power levels substantially above design, have confirmed the soundness of the gas-cooled reactor concept for large scale power production

The contribution to the civil programme 66
by D. R. R. Fair and T. N. Marsham
Large scale experimental programmes on the Calder and Chapelcross reactors for measuring reactivity and stability and testing fuel elements and b.c.d. procedures, have yielded much information of direct benefit to the design, commissioning and operation of the civil stations

Safety aspects of reactor operation 75
by E. L. Desbruslais
With only four main incidents since start-up, all concerning conventional electrical plant operation, experience has shown that the highest safety standards in Calder Hall and the Calder-type reactors are compatible with high generating output

Fuel cycles for magnox reactors 79
by N. L. Franklin, A. Johnson and E. Clough
The choice of a fuel cycle for the civil magnox reactors affects unit generating cost and although careful analyses cannot yet be fully supported by sufficiently accurate data, Calder experience has already made useful contributions

---

The NBS high flux reactor design 84
The National Bureau of Standards' 10MW tank-type heavy water reactor, similar in design to the CP-5, will be used for the study of basic material problems

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Graphite for EGCR, stress relieving at Hunterston, Dresden design modifications, superconducting materials, black void reactor concept, etc. 62

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Metal ring seals, high temperature thermocouples, transistorized nucleonic instruments, ultrasonic thickness gauge, laboratory impeller pumps, etc. 86

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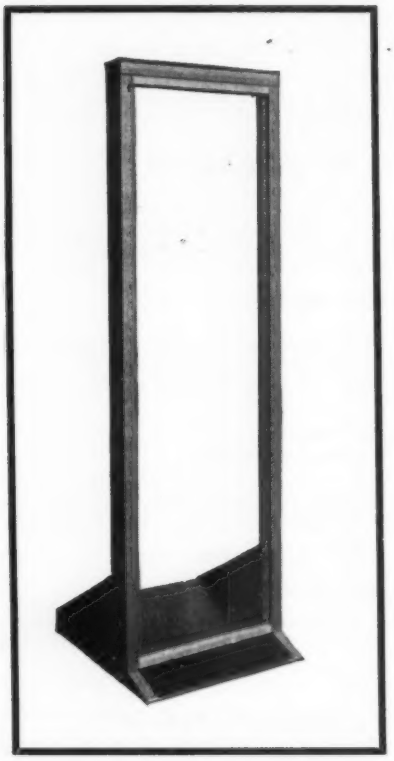

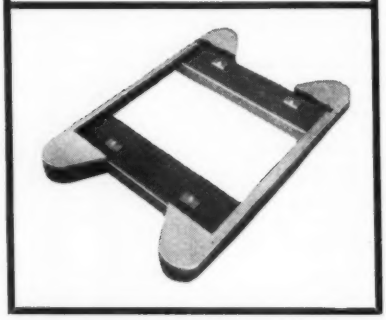

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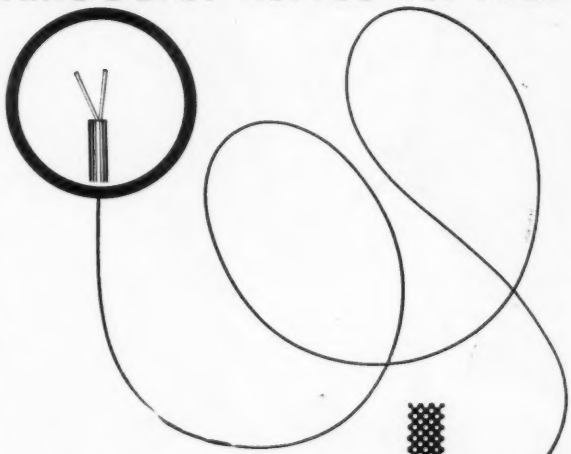
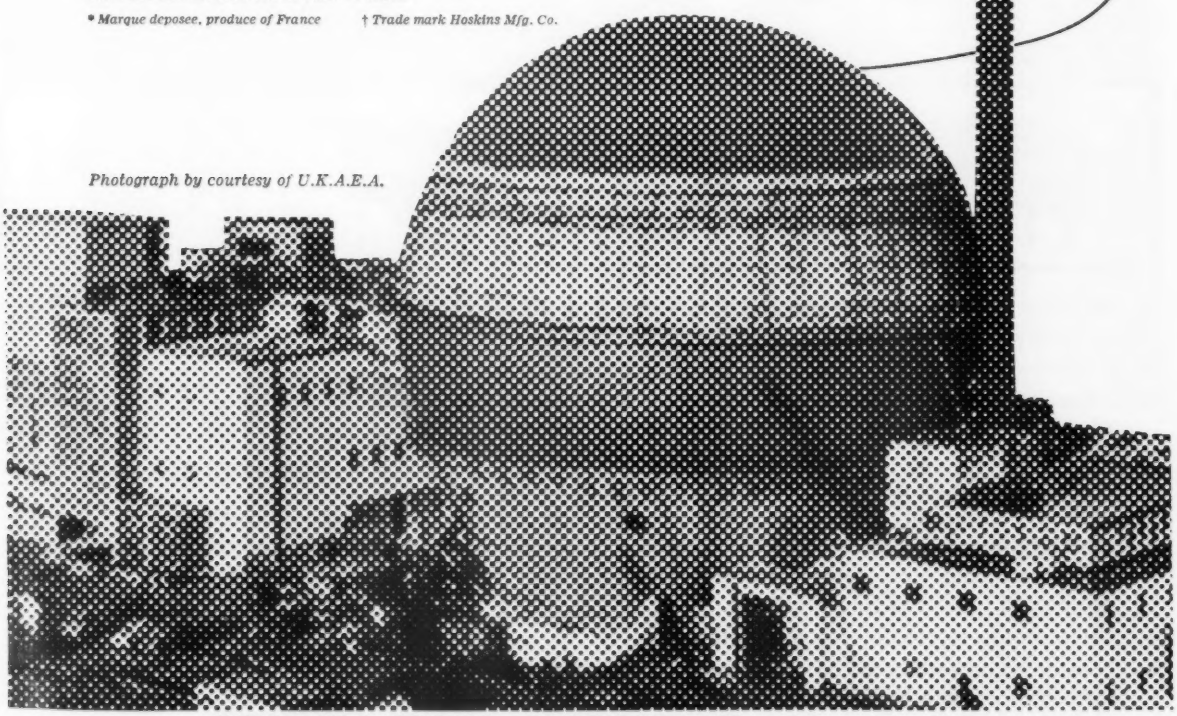


* *Marque deposee, produce of France* † *Trade mark Hoskins Mfg. Co.*

Photograph by courtesy of U.K.A.E.A.



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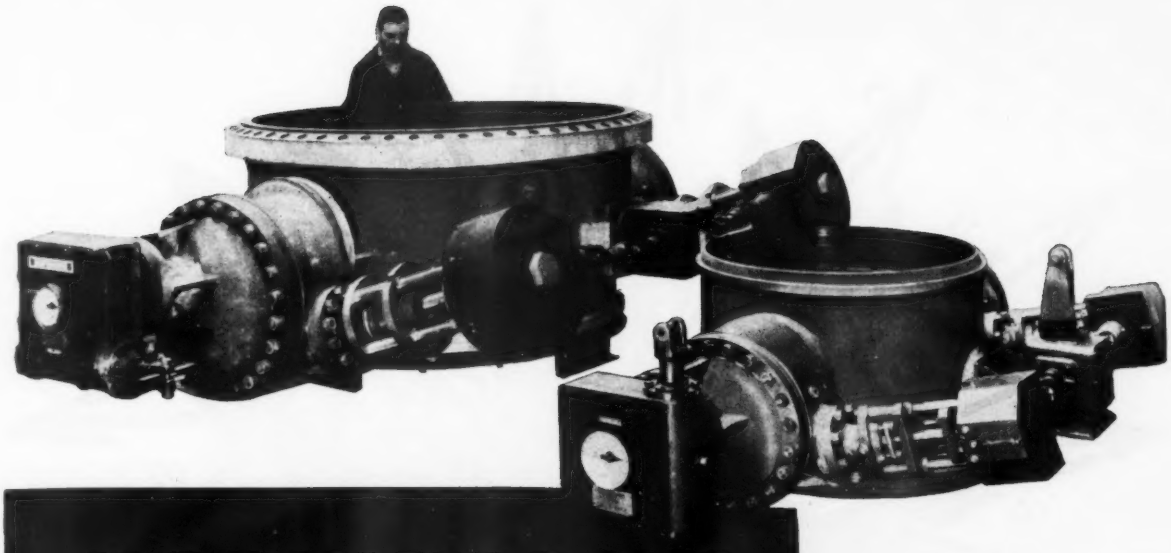
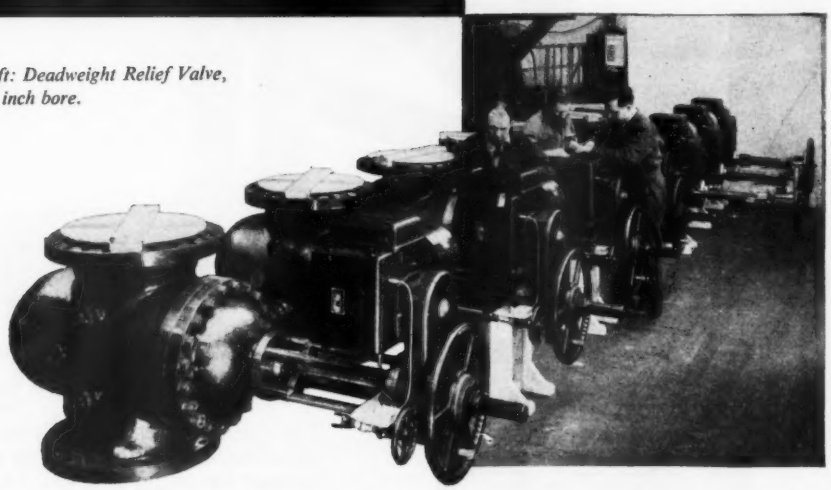


HOPKINSONS' VALVES FOR NUCLEAR POWER STATIONS

Above: "Tansphere" Valves for isolating CO_2 gas between reactor and steam generating plant. Supplied or on order for Bradwell, Hinkley Point, Latina and Trawsfynydd (Valves illustrated are 60 inch and 36 inch bore).

Below: Group of 24 inch electrically-controlled Hopkinson-Ferranti valves for a nuclear power station.

Left: Deadweight Relief Valve, 20 inch bore.



Specialised valves (some of which are illustrated) needed in nuclear power stations are naturally entrusted to Hopkinsons because of their vast experience in the manufacture of valves for exacting duties. But, additionally, Hopkinsons are supplying large numbers of their electrically controlled valves, desuperheating equipment, combined stop and isolating valves, automatic exhaust valves, steam traps and all types and sizes of stop valves.

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Bradwell	**SIZEWELL**

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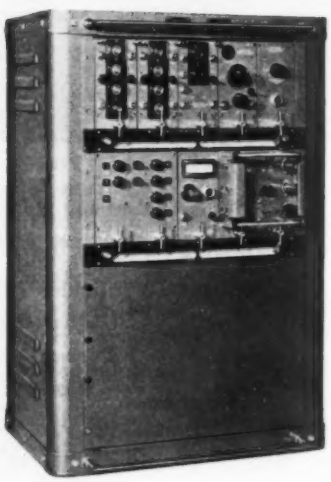

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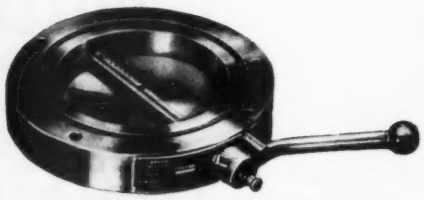
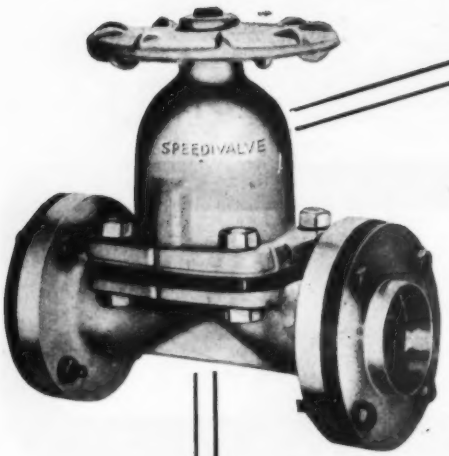
VALVES AND VACUUM





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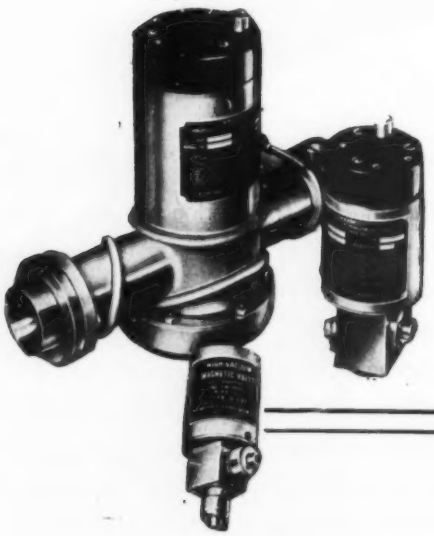

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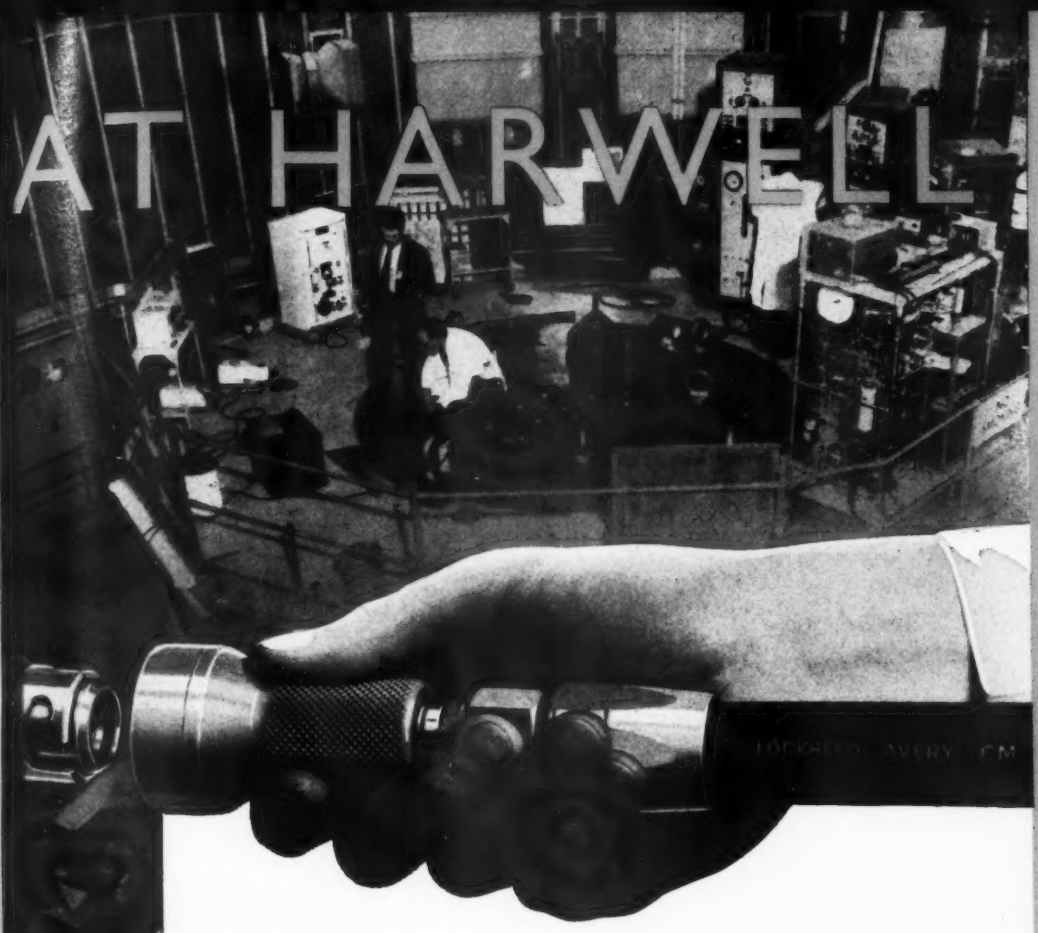
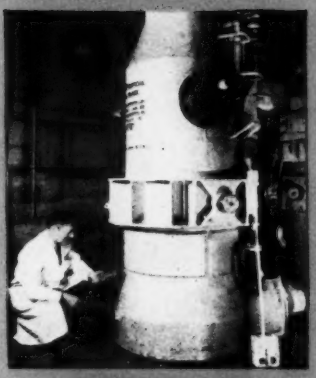
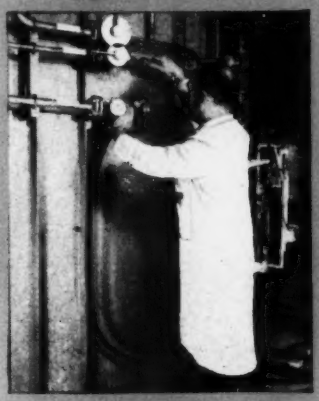




About to supply CO_2 to rig flask



D 20 Transfer station showing couplings and valves

D 20 Transfer station coupling

Replacing cover to coupling after purging thermal column

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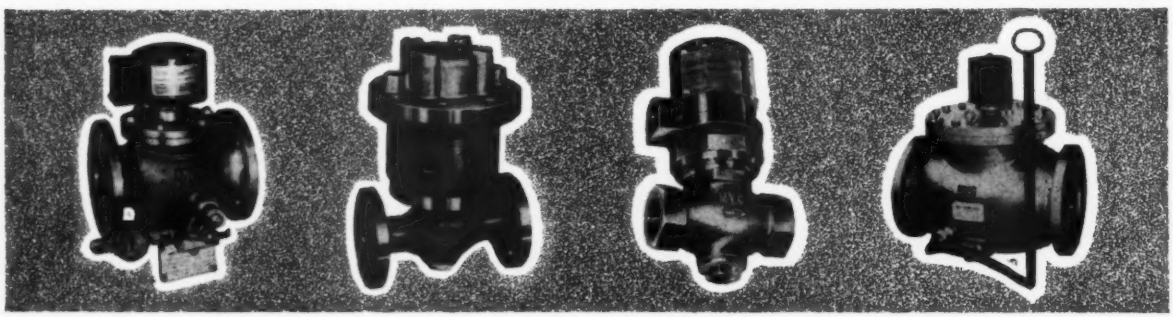

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STRAWS IN THE WIND?

...Yes, indeed, a nuclear precedent for industry

The photograph shows a close-up of one of the seal glands on the pressure vessel wall and biological shield at Berkeley Power Station through which pass some of the 982 "Pyrotenax" thermocouple cables. It is printed by courtesy of A.E.I.—John Thompson Nuclear Energy Company Limited, a Partner Company of The Nuclear Power Group.

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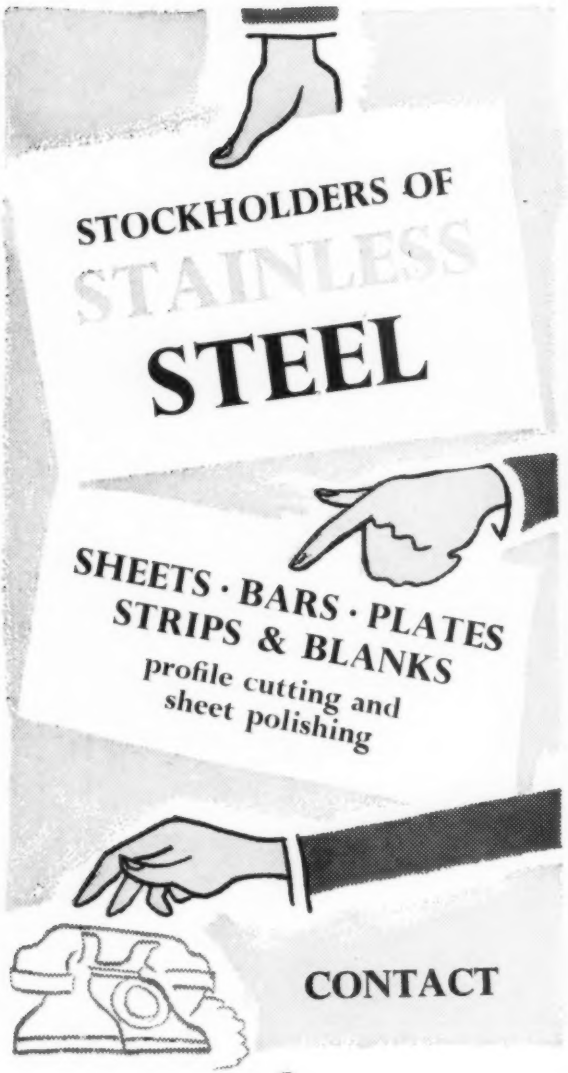

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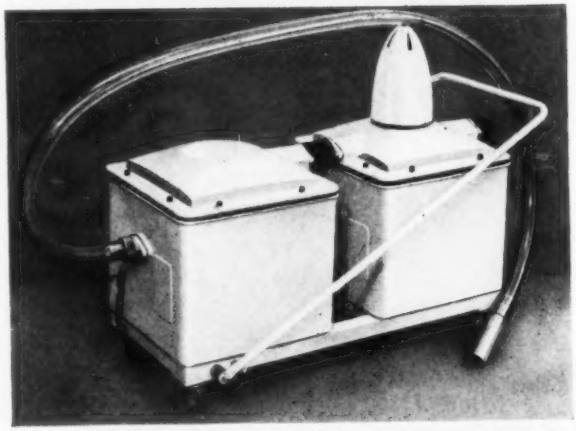

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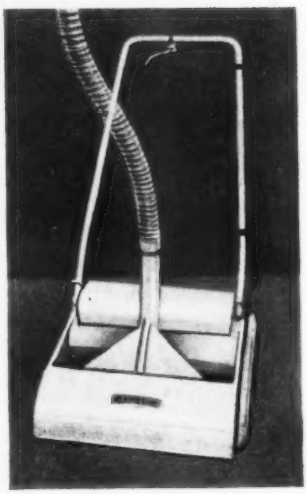

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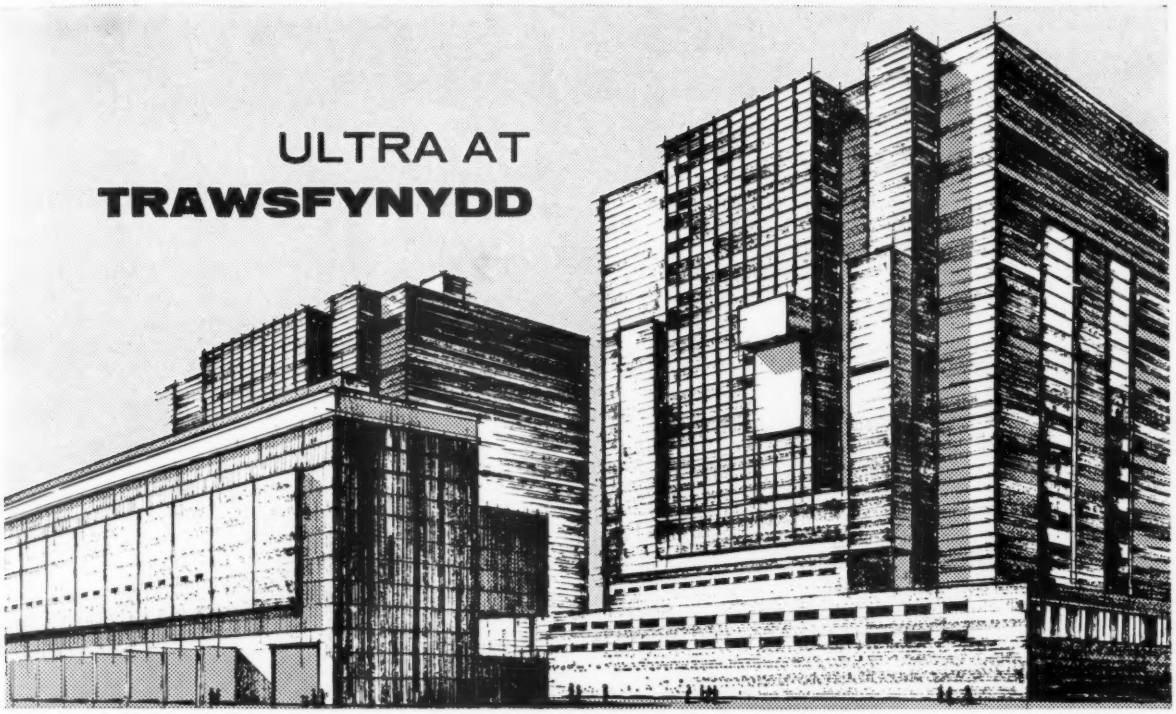

REACTOR CONTROL-SERVO SYSTEMS

The Ultra sector servo control system has been specified for the Trawsfynydd reactor installation being built by the Atomic Power Construction Company on behalf of the Central Electricity Generating Board. Ultra Electronics Limited have specialised experience in the field of servo systems for the close control of combustion in gas turbine engines; this they have successfully applied to the development of equipment for the temperature control of nuclear reactors. In more detail, this specialised experience covers:

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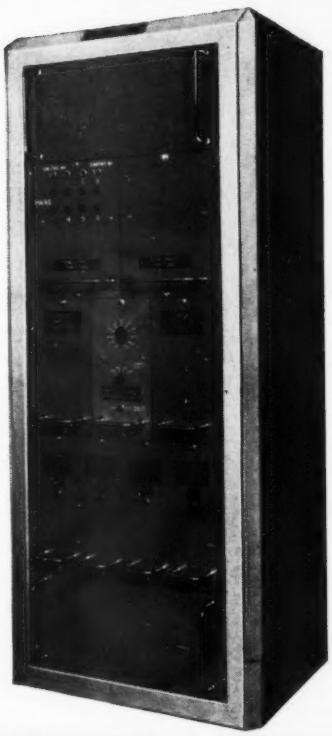
3. *Precision mechanical engineering to fine limits in the manufacture of servo mechanisms thus ensuring the required degree of accuracy and maintaining the overall reliability.*



Nine racks, such as this one, make up each of the sector servo control systems controlling the temperature of the two reactors in the Trawsfynydd installation.

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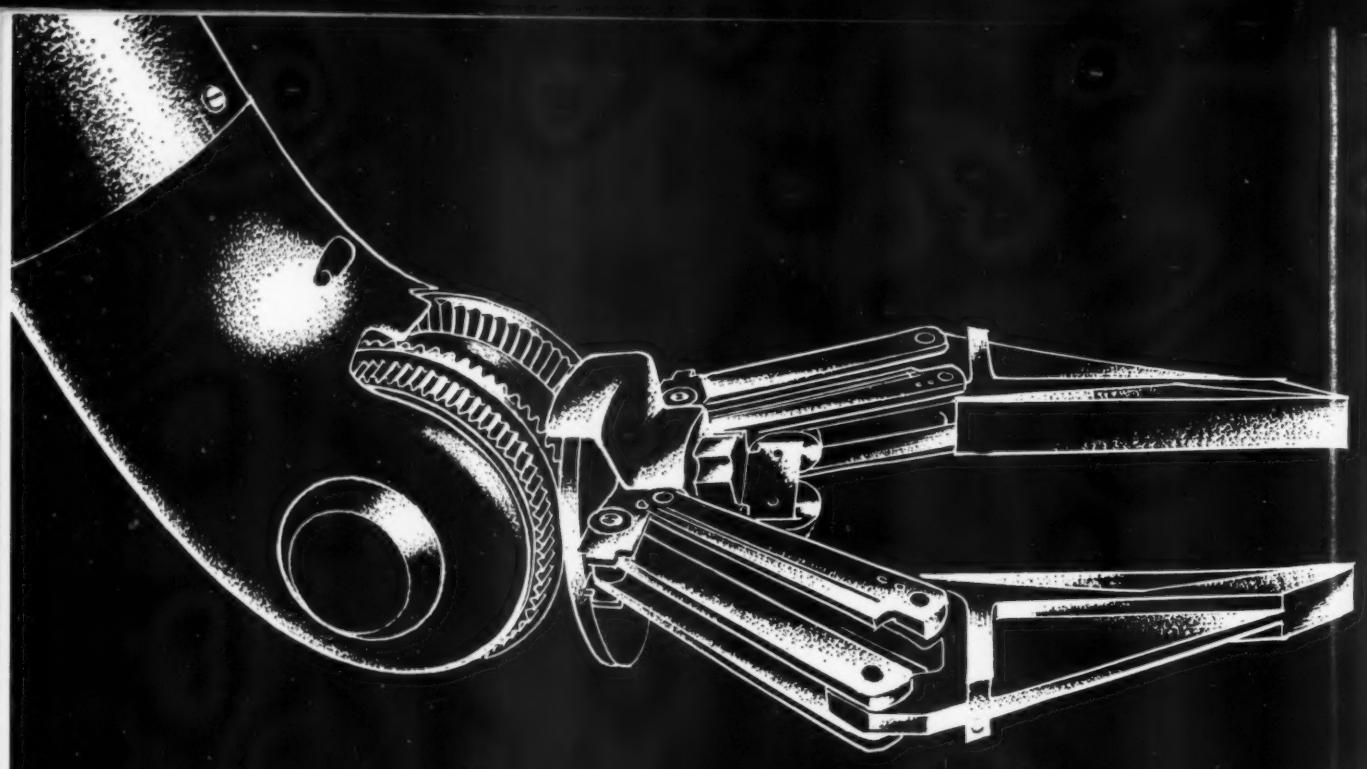
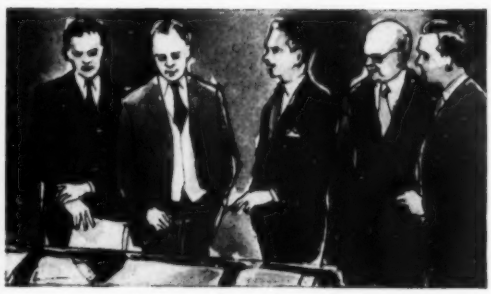
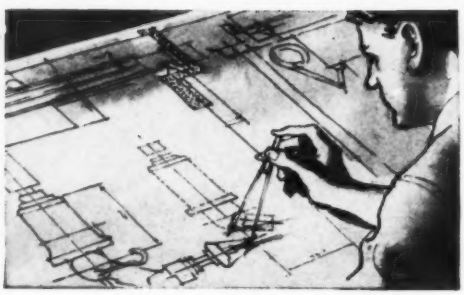


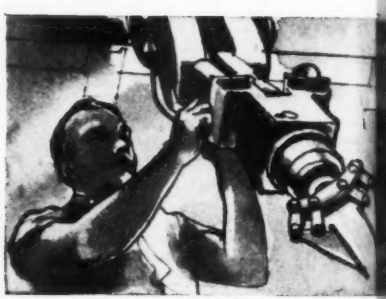
NE8 For lifting and handling R-A materials weighing up to 7 lbs. The equipment has power driven side-swing movements



Consultation at the early stage



Preparing the basic plan



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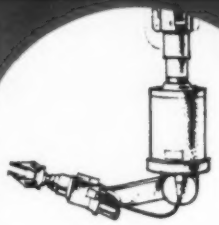
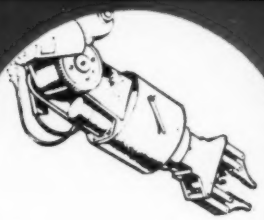


M300 The versatile unit with a lifting capacity from a few ounces up to 750 lb



M100 A low-cost system which offers full cell coverage and a lift of 200 lb

Technical literature on all these types is available from NEL.

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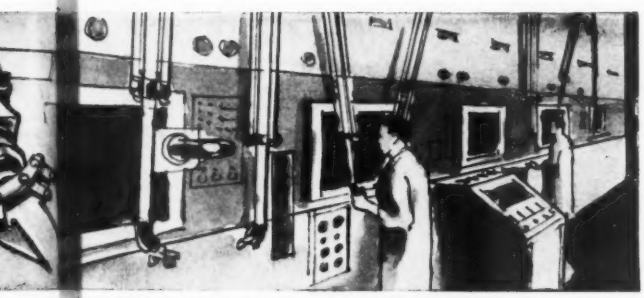

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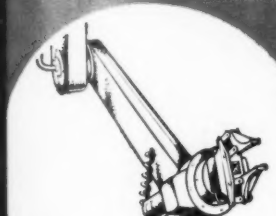
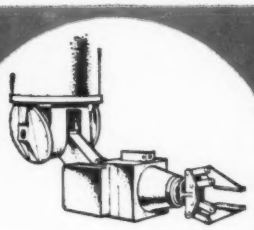
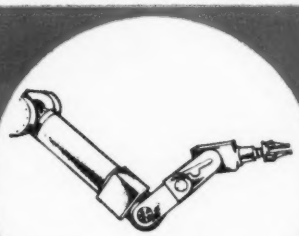


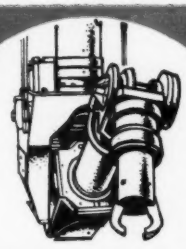
M150 For maximum manipulation in minimum space, e.g. Alpha-Gamma handling in sealed dry box



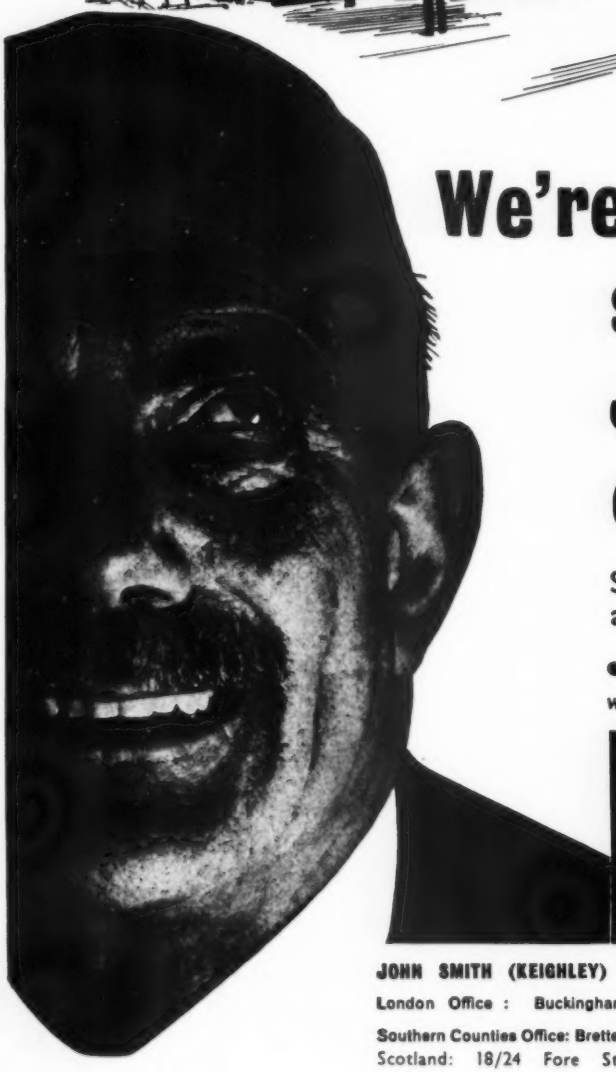
M500 Basically similar to M300 Handles up to 2,000 lb with a fine degree of control



M550 Offers wide versatility in heavy load applications, e.g. 100 lb cantilevered eighteen feet



M700 Heavyweight unit with a rigid hook for lifting loads up to 5,000 lb



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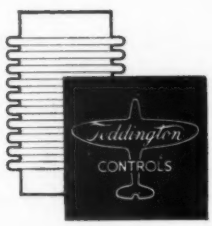

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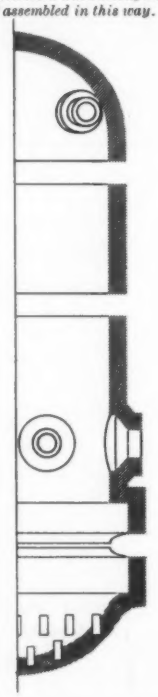

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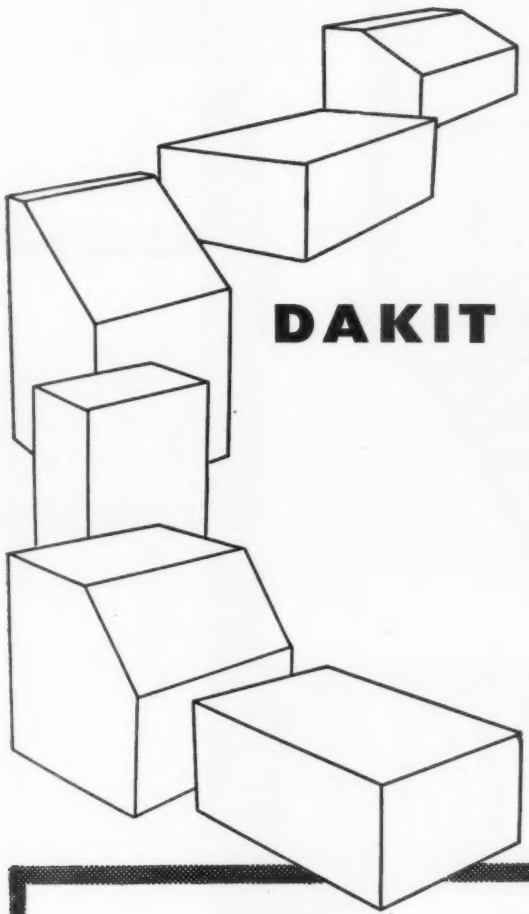

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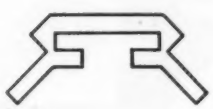

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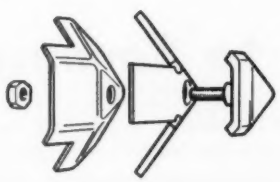
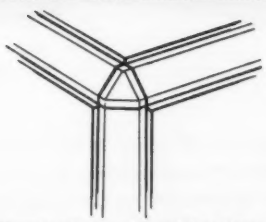


Single nut fixing for quick construction.



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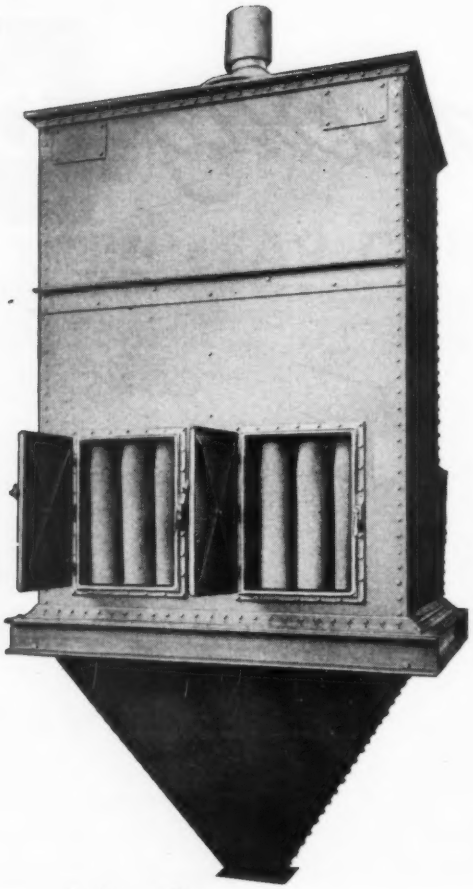

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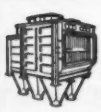

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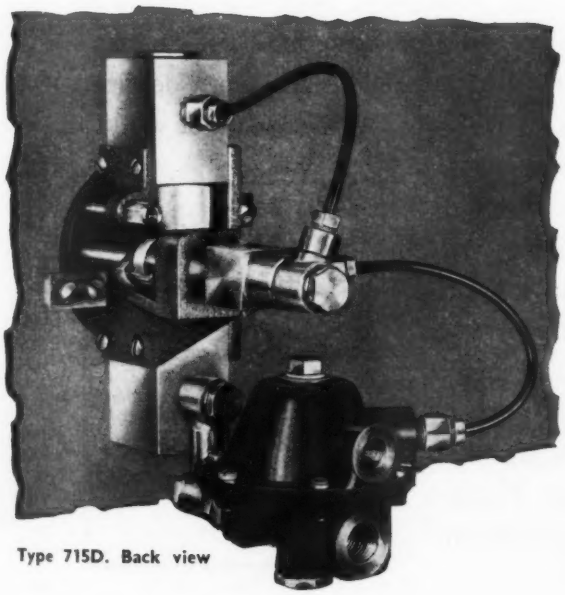

Type 715D. Back view

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715 D.....Indicator, needle valve, and differential pressure regulator

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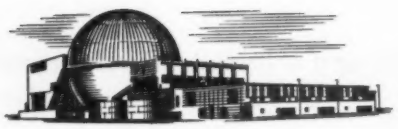

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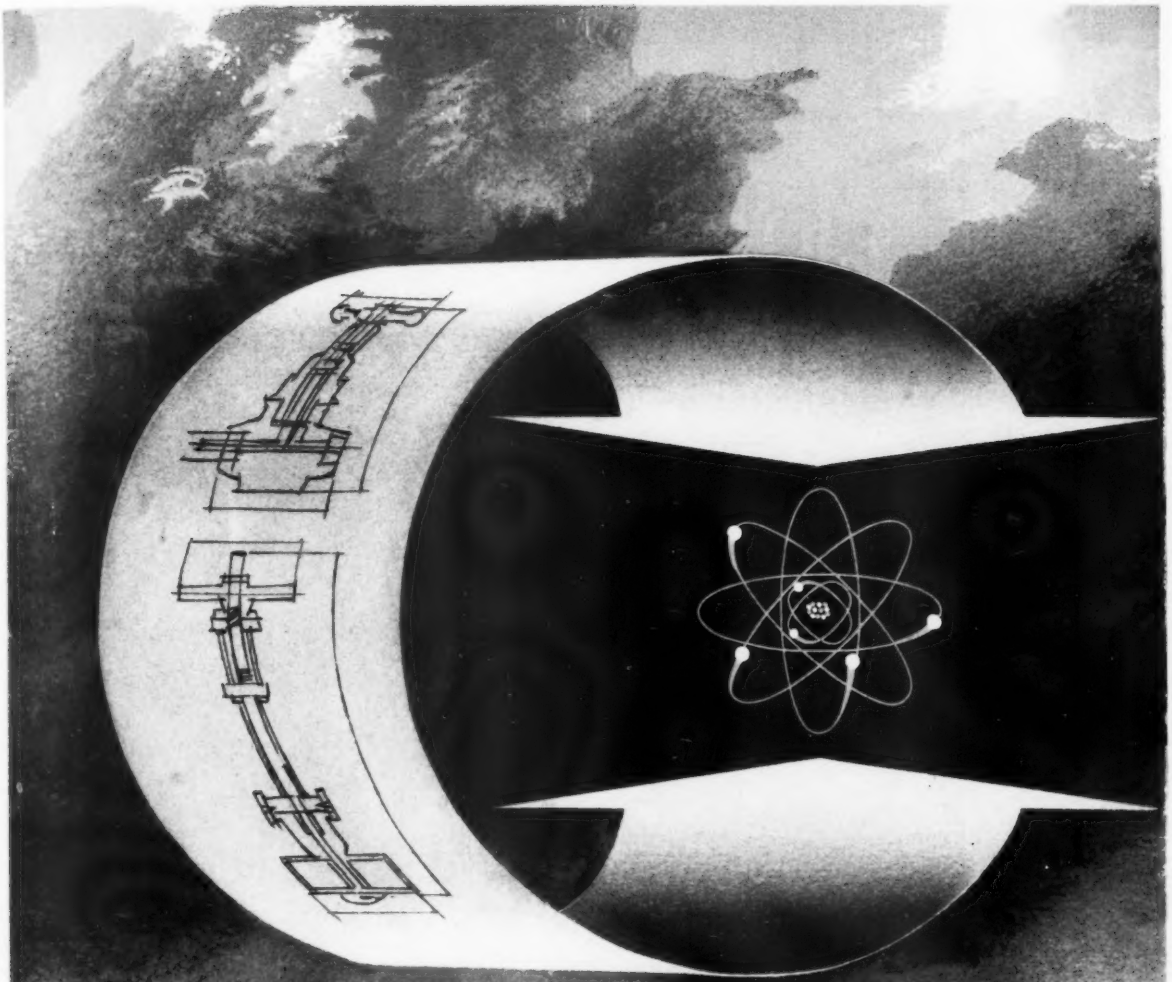

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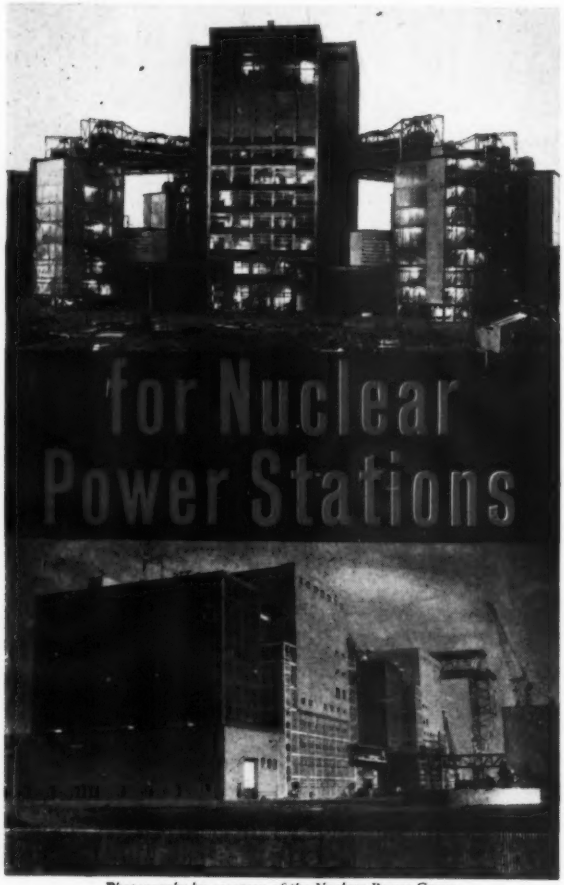

Photographs by courtesy of the Nuclear Power Group.

The first two C.E.G.B. Nuclear Power Stations both make extensive use of M & I insulation; in the electrical plant supplied by A.E.I. to Berkeley and by C. A. Parsons & Co. Ltd., to Bradwell.

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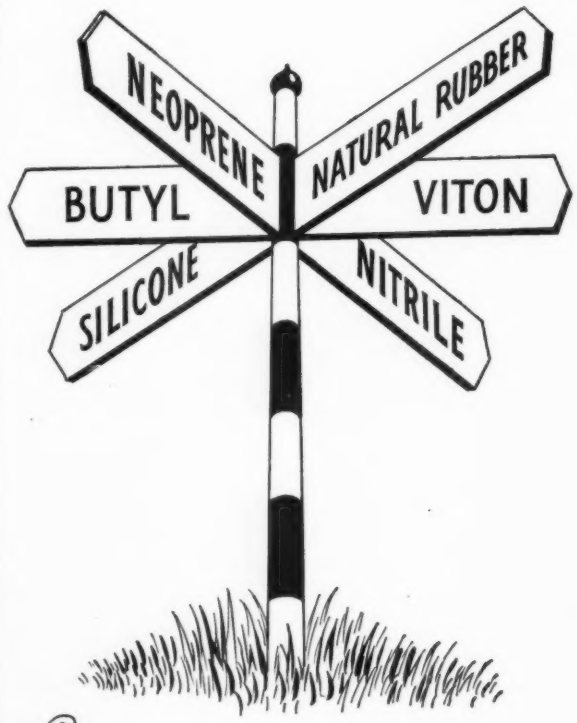

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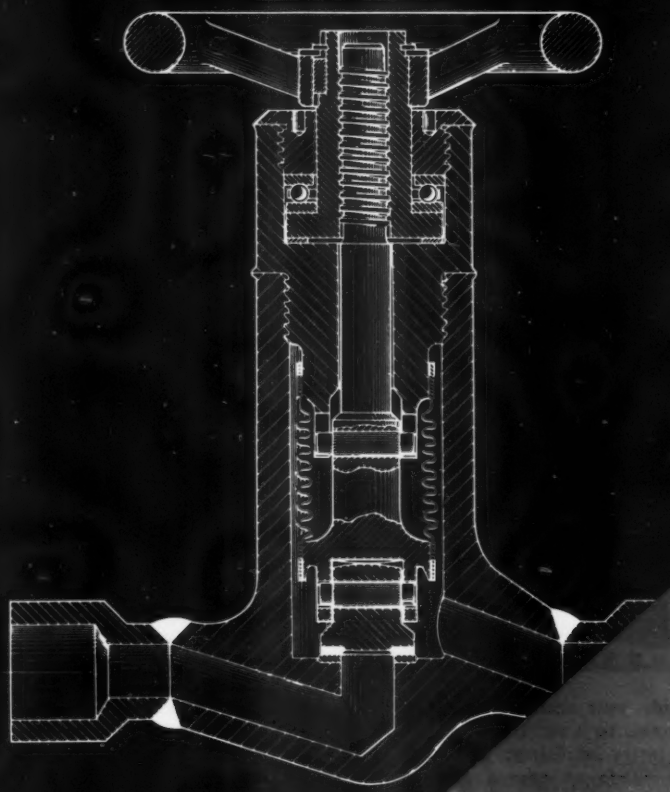

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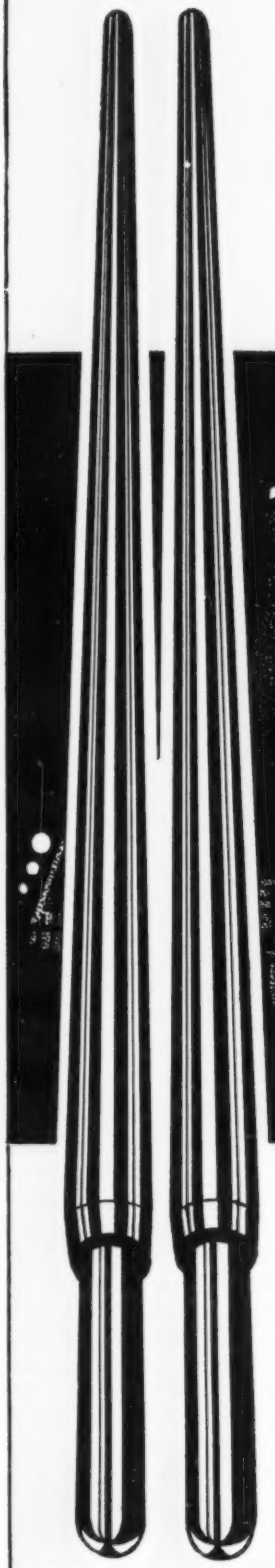

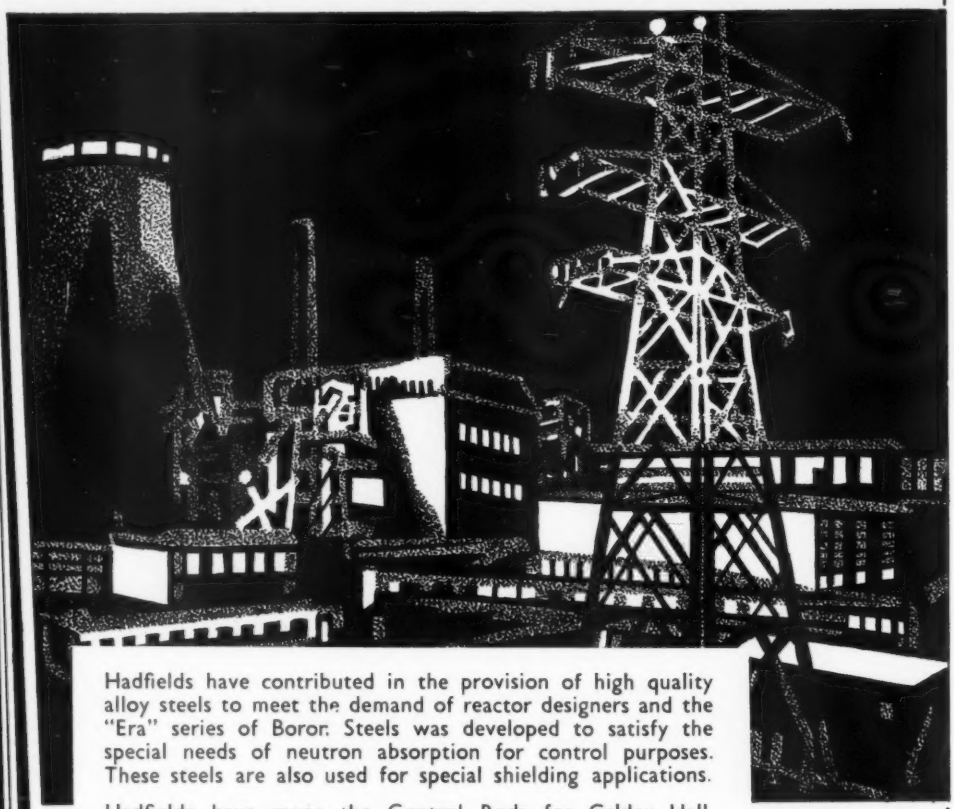

Hadfields have contributed in the provision of high quality alloy steels to meet the demand of reactor designers and the "Era" series of Boron Steels was developed to satisfy the special needs of neutron absorption for control purposes. These steels are also used for special shielding applications.

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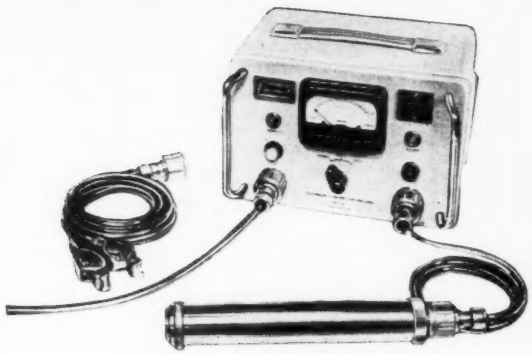

Selective Gamma Monitor type 1080
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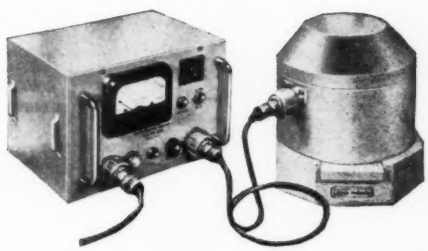
PNL programmes for nucleonic development

PNL is engaged in the design and manufacture of standard and specialised nuclear instrumentation—burst fuel element detectors for reactors, flux scanning equipment, radiation detectors of all types, process control instrumentation, health and defence instruments.

The parallel production by PNL of so much that is complementary in nuclear instrumentation has established within the Company a unique bank of scientific skills and techniques, which is now offered for the development of new projects. The Company's liaison engineers are freely available to assist with problems in their field.



General Purpose Contamination Monitor type 1065
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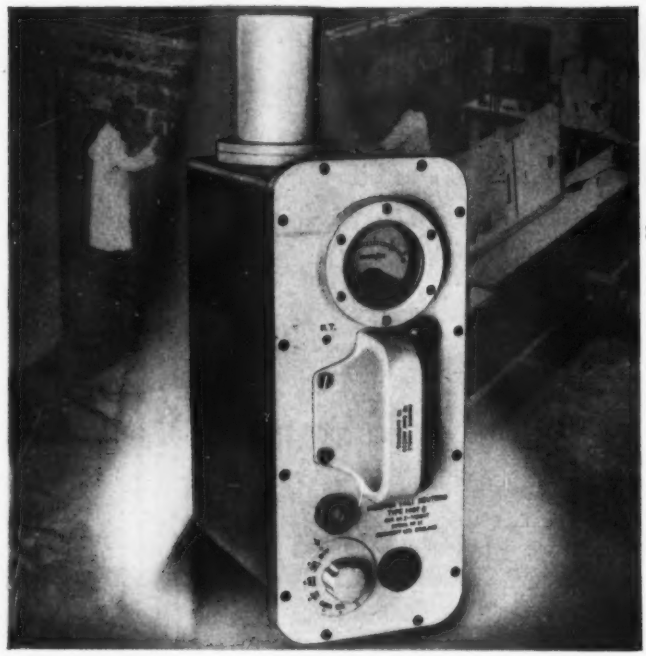

NO ROOM FOR MISTAKES!

SPOTLIGHT ON FAST NEUTRON MONITOR-1407C

Long before the completion of the Calder Hall Station, Burndept development engineers were working closely with scientists from A.E.R.E., Harwell. Out of that co-operation came this Fast Neutron Monitor. Wherever neutron emission needs to be watched, this instrument stands ready to act as a monitor to safeguard the health of personnel. Like all else in nuclear engineering, it has to be virtually infallible. We are proud to believe 1407C will take its place in every nuclear installation in this country and wherever British engineering is appreciated. The 1407C will monitor neutrons in the energy range 0.15 to 15 MeV. It employs a proton recoil chamber as the detector which has a response as a function of neutron energy proportional to within $\pm 20\%$ of the biological dose per neutron.

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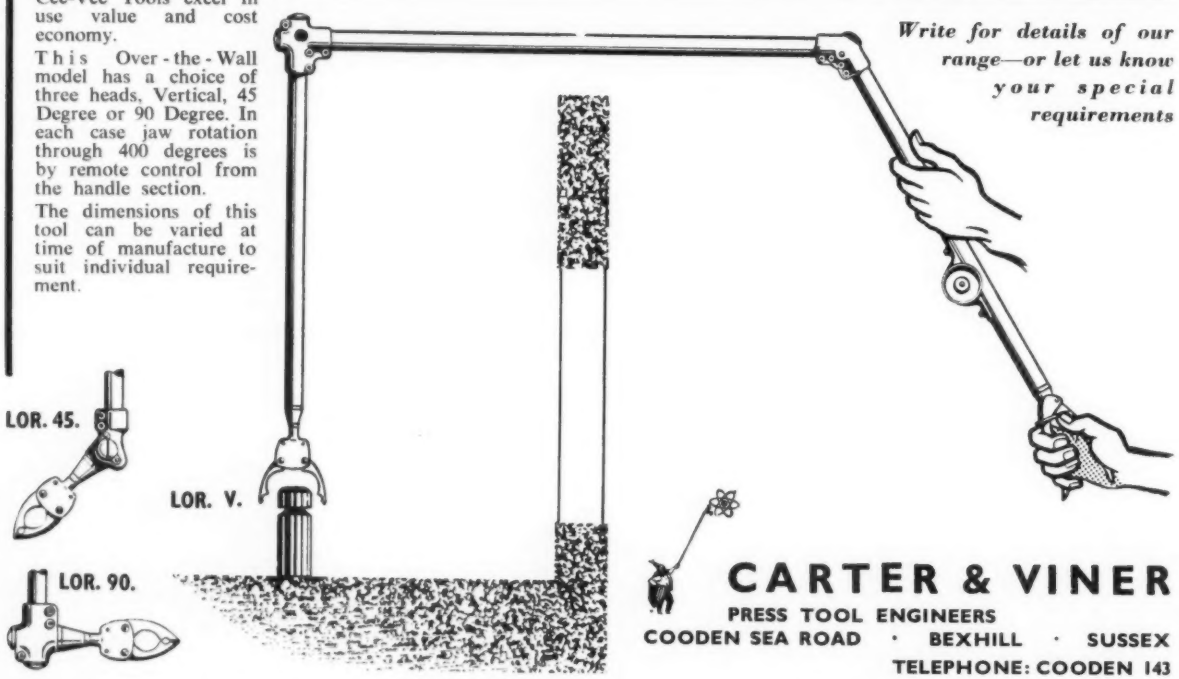

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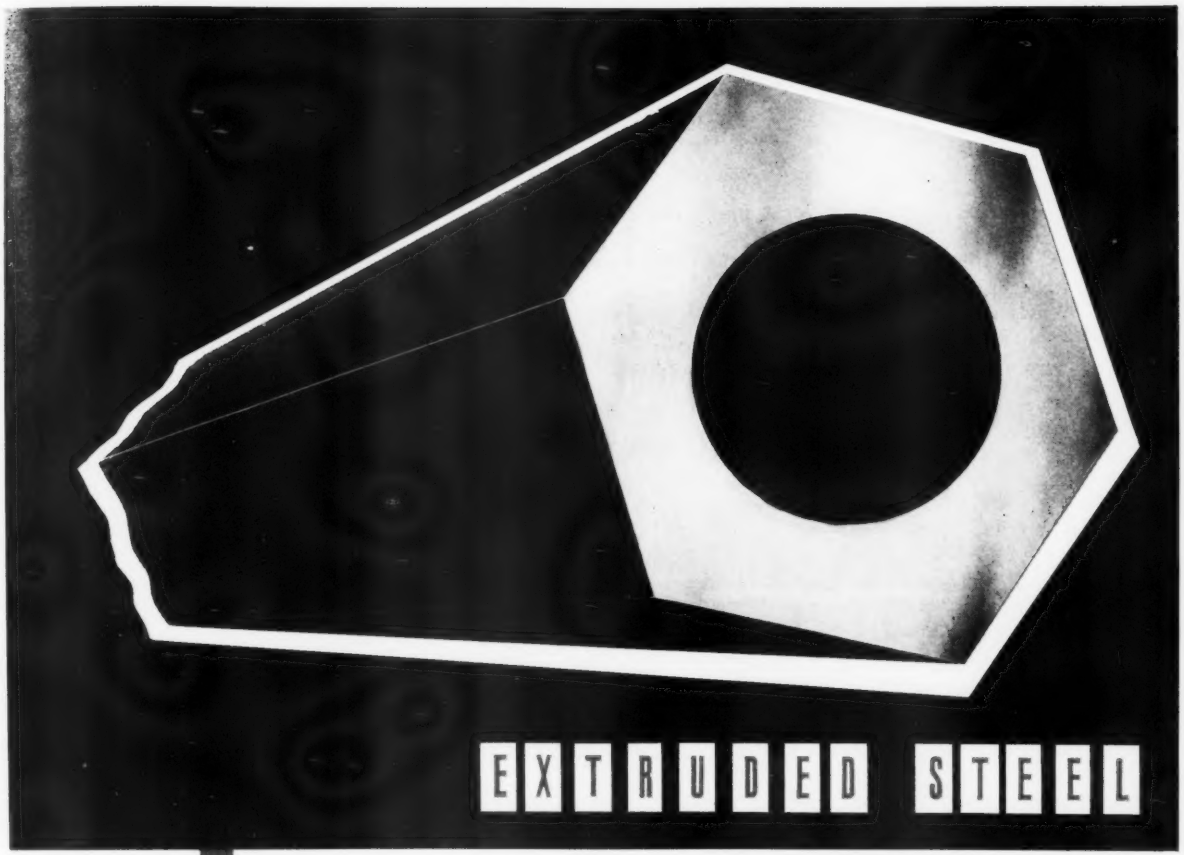

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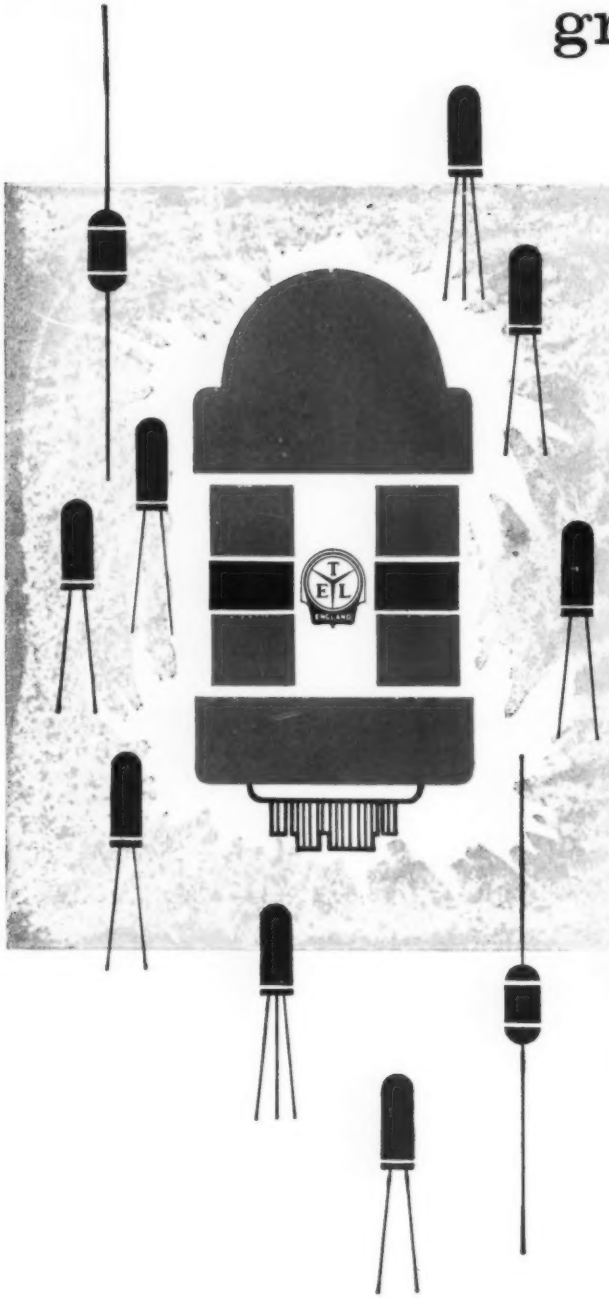

Reliability is not the easiest of terms to define—someone else's definition inevitably takes no account of your own requirements. Yet on one thing all agree, there are only two ways to get greater circuit reliability, one is to choose only the best components and the other to reduce the numbers used. Here difficulties arise for although there are many excellent component alternatives it is only rarely that there becomes available a device which will, without sacrificing performance, allow big component saving.

Trochotron Beam Switching Tubes are such devices.

With the 28V VS.10.K, the Ericsson range has been further extended to give Trochotron reliability at low voltage working and here again component saving is remarkable. For instance, in conventional transistorized decade counters with visual readout, transistors and diodes may number about 90, whereas using the VS.10.K Trochotron this total is reduced by about *ninety percent*.

If, therefore you are concerned with counting, frequency dividing, timing, programming, gating etc., make sure you get greater reliability with fewer components by using Ericsson Trochotron Beam Switching Tubes.

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Heater	**6.3 V**
Max. spade to cathode voltage	**30 V**
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THE PROBLEM:

To accommodate the considerable thermal expansions of the ducting conveying the coolant gas from the reactor to the heat exchangers. The expansion joints must be capable of transmitting the axial duct thrusts (amounting in some cases to over 1,000,000 lbs), while simultaneously allowing a predetermined amount of angular deformation.

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A multiplicity of high tensile steel bars, arranged in two groups into frusto-conical assemblies, and spaced uniformly around the periphery of the duct, transmit almost uniformly the axial forces, while angular deformation is accommodated by transverse bending of the bars.

This restraint works almost entirely on elastic deformation principles, so that the forces involved are both accurately predictable and not variable in time. Furthermore, the complete rotational symmetry of the restraint makes it equally flexible in any direction.

NEWALL'S COLD SWAGING PROCESS was recently applied to the manufacture of high tensile steel bars (up to approx. 42 ins. long) for use in a new bellows restraint mechanism.

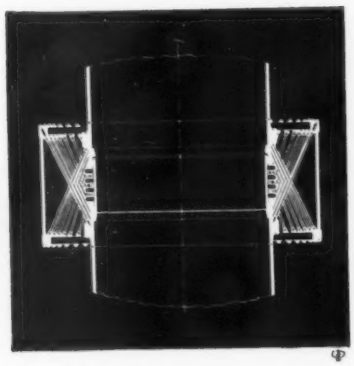
In this assembly, the considerable operating pressures are transmitted entirely by the tension bars, which had to possess the following qualities:

(a) They had to provide a high degree of flexibility.
(b) A uniform tensile strength of approx. 75 tons throughout their length was required.
(c) They had to have a surface completely free from machining marks.

It was obvious therefore that the most satisfactory method of producing such bars was by Newall's cold swaging process, as this company have been pioneers in the manufacture of swaged studs and bolts. Newalls were actually associated with early work in the atomic field when certain swaging operations were required in the planning of Harwell. After extensive experiments, during which a blank was reduced in diameter by approx. 30% (increasing length approx. 40%), the bars have been developed and are now incorporated in the mechanism. In use, they show "extremely high fatigue strength in the high deflection range."

A NEWALLASTIC PRODUCT

Below and at Top Left: Bellows Restraint Mechanism, designed by Richardsons, Westgarth & Co Ltd, for the Trawsfynydd Nuclear Power Station.



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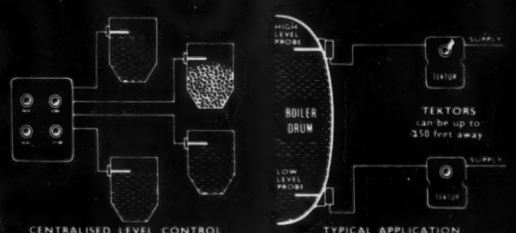

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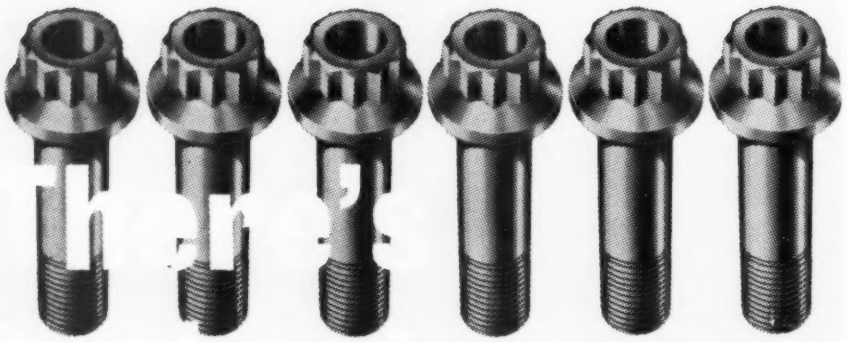

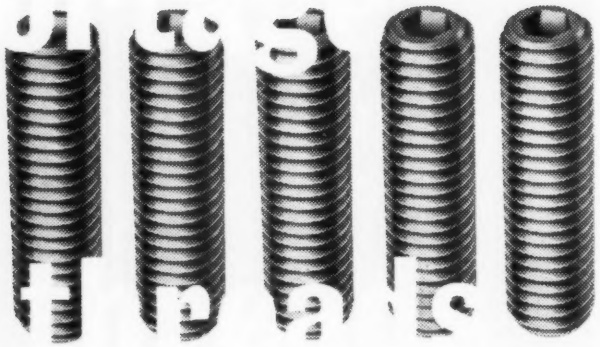

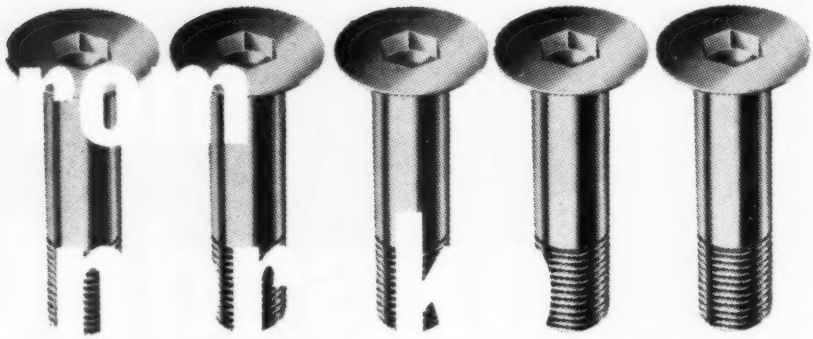

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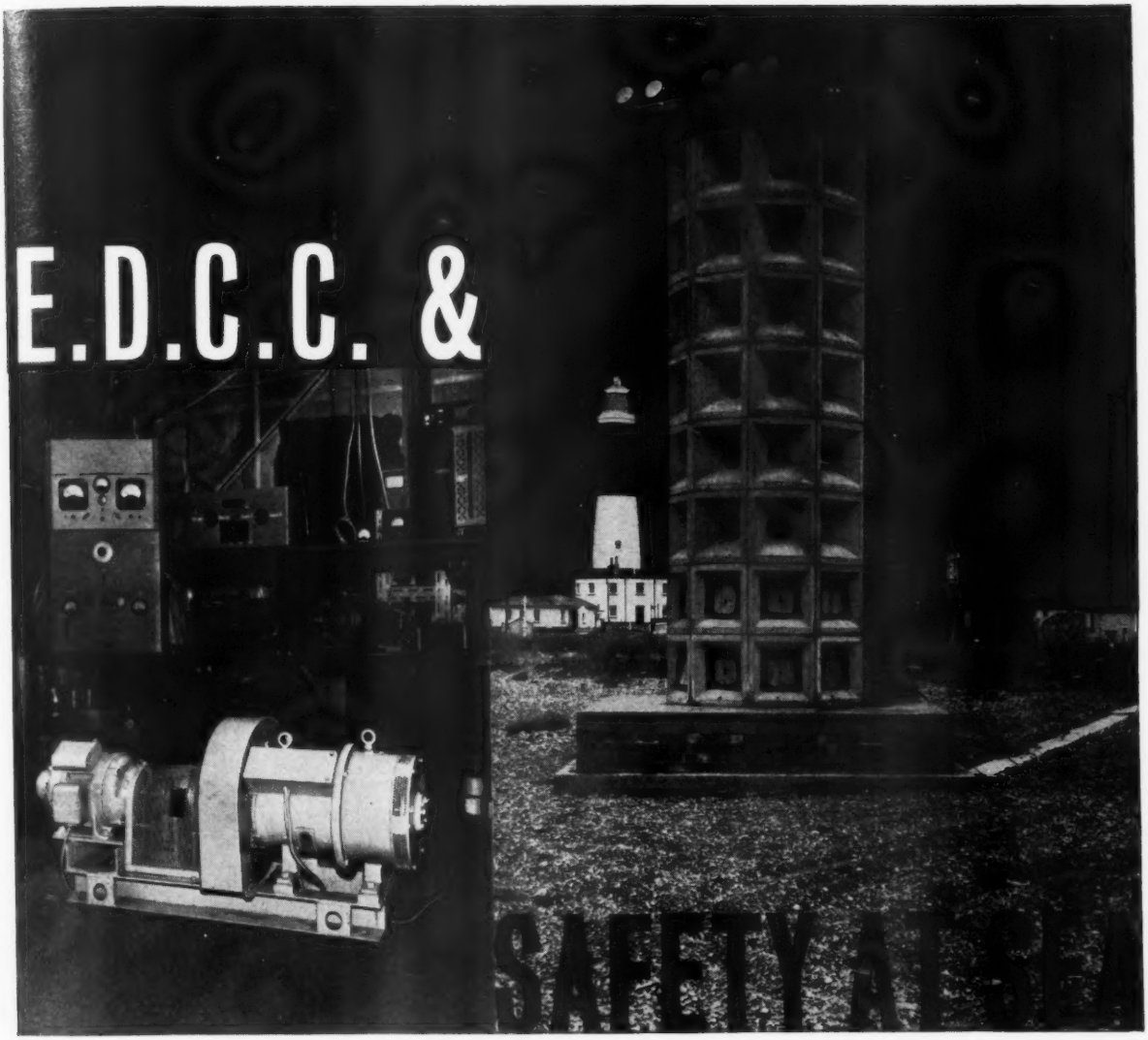

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Thoughtful production executives who want to know more have only to write for the book, *'Selecting Your Cutting Oils', to Lubricants Dept., Shell-Mex House, London, W.C.2.*

SHELL

SHELL CUTTING OILS

Nuclear Power NOVEMBER 1961 VOLUME 6 NUMBER 67

VIEWPOINTS letters to the Editor

Beryllium's future

SIR: As the UKAEA points out in their latest annual report, ' Tests on the corrosion of beryllium in carbon dioxide have shown that, under the higher temperature conditions in the AGR, more corrosion can take place than can be tolerated in the AGR . . . Some beryllium clad elements will be loaded into the cooler parts of the reactor followed by a gradual loading of beryllium clad elements into the hotter parts as material of better corrosion resistance is obtained.' The above statement confirms that there are some corrosion problems which require solution, but to interpret this as a decision to ' drop AGR beryllium plans ' as you have stated, in your August issue, page 53, is unwarranted.

Beryllium metal in dry CO_2 is perfectly satisfactory at the intended operating temperatures, we understand. However, in CO_2 containing water vapour, while some beryllium is still satisfactory at these temperatures, other samples of beryllium do corrode at a rate faster than desired. The extent of this present uncertainty is the basis for the decision to have less beryllium in the first loading of the AGR than previously planned. However, there are several possible ways of solving this problem, and all are being looked at carefully both in the UK and the US. These include the obvious approaches of:

1. Drying the CO_2 gas.
2. Substituting helium for CO_2 as the coolant gas. (Beryllium does not corrode in helium gas at the AGR operating temperatures, even if the gas contains some water vapour.)
3. Modifying or improving the beryllium so as to make all pieces corrosion-resistant to CO_2 containing water vapour, in a manner similar in principle to the development of the water-corrosion-resistant ' Zircaloy ' alloys. Intensive research and development work in this area is proceeding in many laboratories, and I see no reason why this work will not ultimately lead to a successful solution of this problem.

Regarding the alternate use of ' stainless steel ', it should not be assumed that the special type of steel tubing required with its extremely thin wall, necessary to reduce neutron absorption, is without its own special problems, and it is easy to over-simplify this situation.

With reference to the dropping of the GNEC-gas-cooled reactor in the US, this was not occasioned by reasons pertaining to beryllium, but rather to broader aspects of technical and economic factors pertaining to the over-all reactor concept itself in relation to other neutron concepts. As you know, the USAEC Experimental Gas-Cooled Reactor Project at Oak Ridge is proceeding energetically, and we fully expect to see beryllium clad fuel elements used in this reactor.

The uses of beryllium in nuclear energy, space and missiles applications are increasing steadily, both as these programmes increase in size and as the ' state of the art ' develops. This development is going on at an ever-increasing rate. There are many reactor systems which should be looking towards beryllium metal and/or beryllium oxide, and in this connection you may find the attached report* on this subject prepared for us by NDA (now United Nuclear) of interest.

N. W. BASS
VICE PRESIDENT

The Brush Beryllium Co,
Cleveland 3, Ohio

* Application of beryllium metal to nuclear power reactors Report NDA 2653-1 November 30, 1960. 66pp.

Bradwell criticality

SIR: In your September 1961 issue, in *Worldview*, I read with alarm that at Bradwell, ' Criticality was achieved here at 10.36 tonight *during the loading* of the 464th channel when a power of one watt was generated ', (my italics).

Have The Nuclear Power Group and the Central Electricity Generating Board co-operated in a commissioning procedure of going critical while hand-loading of fuel is in progress?

In this report I also read that the channels were loaded each with eight fuel elements, and that there are 3275 fuel element channels in each reactor. Are not both these figures incorrect?

B. LOVE

Seamill,
West Kilbride, Ayrshire

The Technical Editor writes: the loading to criticality procedure takes place under a system of permits granted to the station licence holder, in this case the CEGB, by the Inspectorate of Nuclear Installations of the Ministry of Power. The Inspectorate assures itself of the safety of the procedures before granting the permit to load. In both Bradwell and Berkeley fuel was lowered from the pile cap to the core top and then into the reactor by hand winches.

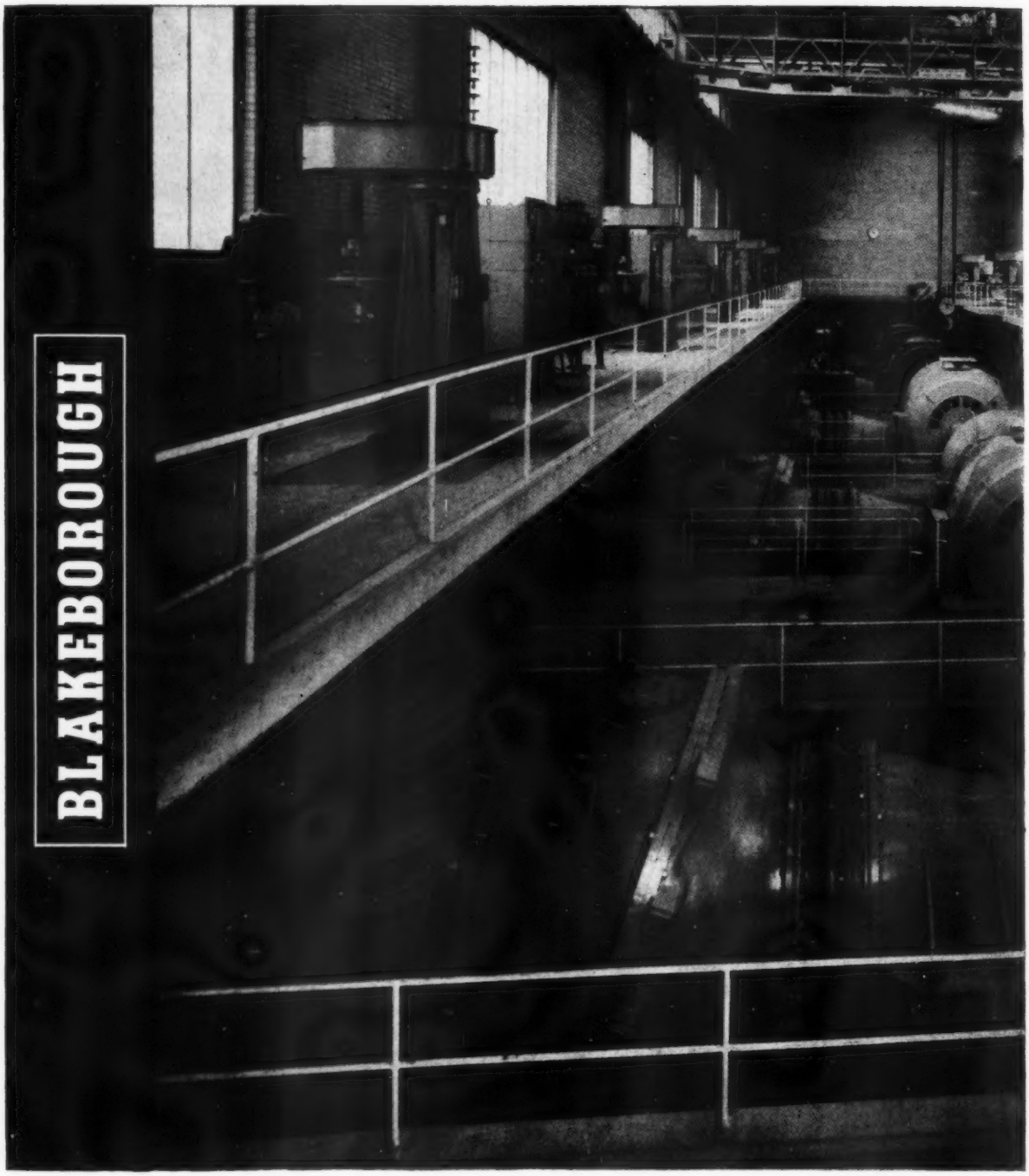
The loading takes place with control rods locked in position. Periodic measurements of the neutron flux are taken with personnel *out of the reactor* and with the control rods out. A graph taken of the inverse of the flux measurement against the number of channels loaded gives the number of channels needed to achieve criticality. This gives the critical size in terms of the bare graphite lattice plus fuel.

As far as Bradwell was concerned 464 of the 2564 channels were loaded with 36·6 tons of uranium to achieve criticality. In fact super-criticality was reached with control rods out since a power output of 2 W was measured. There are eight elements per channel at Bradwell but only seven per channel were loaded. For Berkeley the critical loading was found to be 52·1 tons of uranium in 744 channels.

A full account of the approach to criticality for both Bradwell and Berkeley, together with pictures, was included in the October issue, pages 59-61.

Welding survey

The following omissions and errors in our October Survey, pages 70-74, have been brought to light. The Carl Zeiss electron beam welder marketed by Degenhardt (p. 71) should be entered under ' Special Processes—electron beam '. Under ' Electrodes . . . ', London & Scandinavian Metallurgical Co. Ltd, should be included for welding rod coatings. Under ' Non-destructive Testing ' it should be noted that the High Voltage Engineering Corporation, together with the associated UK company High Voltage Servicing Co Ltd, supply compact microwave electron accelerators for X-ray inspection. The Manchester Oil Refinery (Sales) Ltd should be included under ' Penetrants '.



(Photo by courtesy of C.E.G.B.)

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OPINION

Calder's fifth Anniversary

NO ONE VISITING Calder Hall can come away without feeling that this is, and has been, a tremendously successful experiment. So much so that it is hard to realise that it was only five years ago, on October 17, 1956, that Calder Hall No. 1 reactor was connected to the Central Electricity Generating Board's national grid — the first time that electricity from a nuclear power station was delivered to a national distribution system. This singular event heralded the start of Britain's civil nuclear power programme and the end of a five year programme which began with a design study on a dual purpose reactor system in 1951.

Today, after a start which began without a sure knowledge of how the gas-cooled system would work, 24 reactor operating years have been recorded on Calder Hall and Chapelcross reactors. And looking back, this five year cycle has been one packed with solid achievement of which the most impressive have been the uprating of the reactors and the load factors obtained. In 1960-61, for instance, the average load factor was 88% but Calder No. 4 during this period had a load factor of 95·6% without any fuel element failures. The time needed to recharge the reactors has steadily decreased to a scheduled four weeks, though here again an improvement has been recorded, this time on Calder No. 2 which was recently recharged in 24 days.

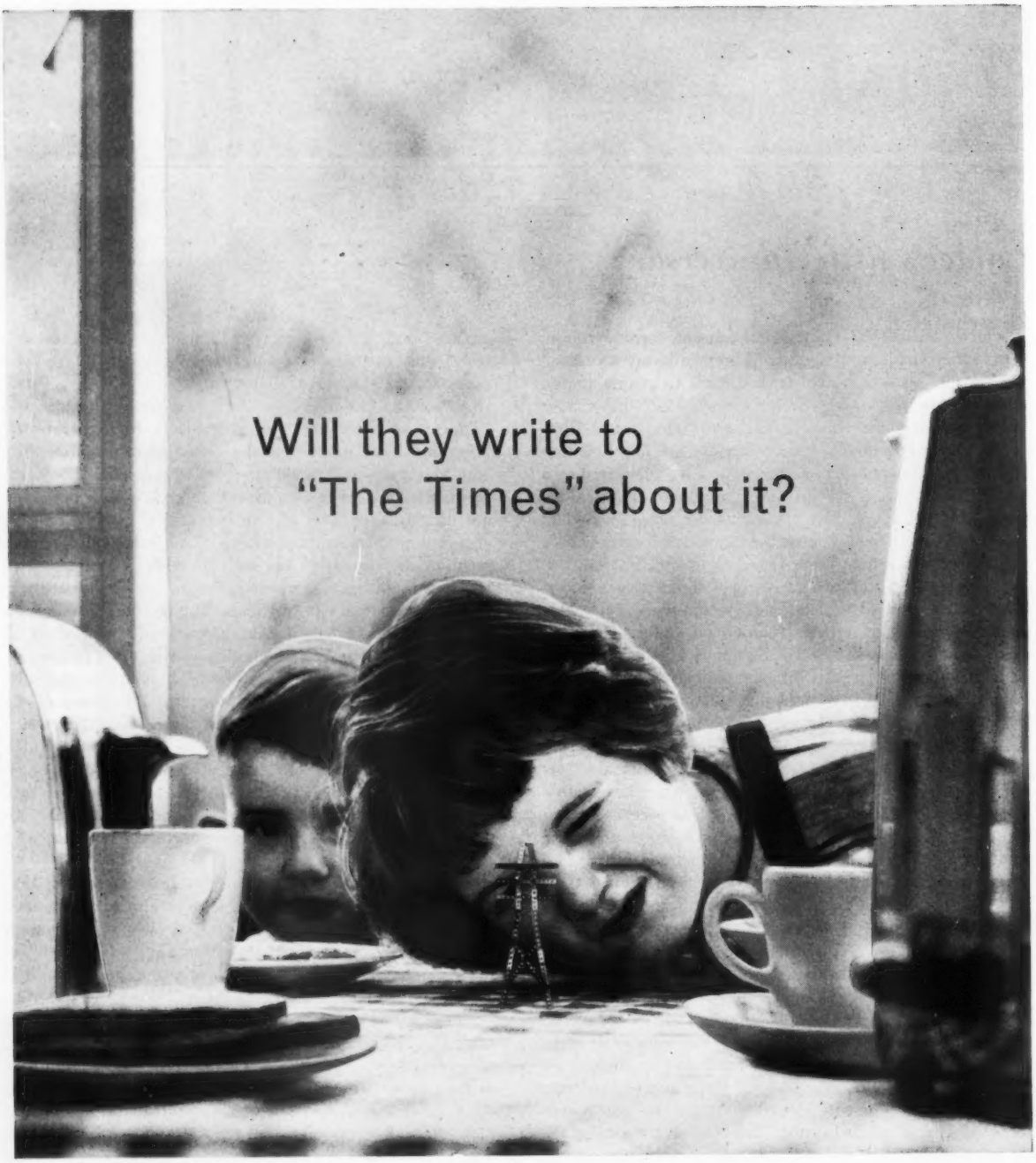
The maximum can temperature has been increased to 418°C, a ten degree increase over design, and with spare blower and turbine capacity, it has been possible to raise the electrical output. Further increases in output have come from reblading the turbines — three have already been completed at Calder — to uprate output from 34·5 MW to 45 MW. In addition, the cost of reblading will be recovered in a year's time through the sale of the additional electricity. There will still be heat on hand and by the end of the year, steam representing about three quarter's of one reactor's output will be supplied to the Windscale Works for process and space heating. The cost will be some 35-45% less than that supplied by the conventional steam raising units now used and these will be shut down when the scheme is completed next year.

Compared with fossil-fired stations, maintenance time at Calder is considerably less, particularly for the boilers. These are now inspected during the planned maintenance periods. Operational safety, too, has been most impressive. All the major incidents have concerned the conventional equipment (see Desbrulais, this issue).

Equally remarkable has been fuel element performance with only five or six real fuel element failures recorded. (There have been about 200 failures connected with the low ductility of the magnox used at low temperatures.) The number of failures, mainly concerned with the porosity of the weld which escaped detection, is now reduced through an ingenious pressure test (see Fair and Marsham this issue) thus further decreasing the amount of outage time necessary for discharge of failures.

As well as keeping to production schedules, Calder and Chapelcross have been used extensively for experimental programmes in support of the civil programme (see Fair and Marsham, and Franklin *et al.*, this issue). Some experiments have dealt with aspects of civil station operation not directly applicable to Calder reactors, namely, on-load charging and reactor stability. Two especially deserve mention. In one, fuel was left in Calder No. 3 for two years without recharging to examine reactivity changes during irradiation. It has been shown that equilibrium reactivity will be attained at a maximum irradiation of 4400 MWd/t. The result, combined with the favourable performance of fuel elements, augurs well for the civil stations. The other experiment concerns the ability of the Calder type reactor to withstand temperature transients. A reactor at half power had the blowers tripped and a temperature transient of 130 degC was recorded which returned to just above the original fuel element temperature in about three minutes. This was in good agreement with calculations and represents a high degree of confidence in the behaviour of the reactor.

It is this confidence which is such a feature of the station for the staff display a remarkable degree of self assurance which is also coupled with modesty. It would be pleasing to report that this spirit of enthusiasm was shown by the Authority generally but sadly, even the most optimistic would admit that morale in the AEA is not what it used to be. In part this is due to the obvious letdown that has come after the unrelenting effort which brought about Calder. In part, too, it reflects the lack of purpose in the Authority at the moment for no fresh objective has appeared and the AEA gives the impression of over-bureaucratization and lack of leadership. One also suspects that lack of an adequate internal information policy is giving rise to the many rumours of an impending change which has been reinforced by the lengthy delay in announcing a successor to Sir Leonard Owen. It was announced in September that Sir Leonard was joining a commercial organization on October 1, but up to the middle of October no announcement about his successor had been made. As it was known some 12 months ago that Sir Leonard was due to retire this year, this time lag would seem to indicate either a lack of suitable successors or a policy change. But this is only one aspect of the slowing down of the Authority. What can be done is difficult to detail but unless some fresh objective is found, the malaise will continue and in the light of the achievements at Calder Hall, this would be a pity.



By the time these children are ten years older, Britain's power demands will have doubled. But the number of transmission towers will *not* have doubled. On the contrary — because the Central Electricity Generating Board is adopting 400,000 volt transmission, fewer new towers will be needed. The new power system will use some existing towers, suitably reinforced, and a limited number of new, slightly taller ones. By Act of Parliament, the C.E.G.B. must provide an efficient, economical electricity supply, while preserving visual amenity as far as possible.

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WORLDVIEW

the month in atomic energy

EUROPE

The AGR—CEGB makes first move

London First steps towards building an advanced gas-cooled reactor (AGR) have been taken by the Central Electricity Generating Board. The annual report issued by the Board says that preliminary consideration has been given to a more advanced type of reactor based on the AGR being built at Windscale.

Both the CEGB and the AEA have carried out joint studies on a civil AGR, one of which has confirmed the promise of considerable reductions in capital cost and in total cost of power generated compared with magnox stations. This study was carried forward in more detail during the past year (AEA Seventh Annual Report).

The CEGB report adds that developments of reactor pressure vessels made of reinforced concrete instead of steel plate are being encouraged. Considerable effort was devoted to designing gas-cooled reactor cores which accommodate the changes in physical properties that occur during the irradiation of graphite. Where necessary, the report adds, modifications were made to cores of reactors under construction.

Other studies being undertaken by the Board include the assessment of a magnesium-zirconium alloy fuel element can. Studies have shown that the life of this type of can shows a significant improvement over the magnesium alloy can supplied to the first reactors.

General points from the report are that the Board, during its third year of operation, had a deficit of £1·5 million ; this compares with surpluses of £5·4 million for the previous year and £10·8 million for 1958–59. The deficit was partly due to unexpectedly heavy demand during the autumn of 1960 (a 17·4% increase) which made the Board operate older, less efficient stations to a greater extent than planned. Expenditure on fixed assets, at £196·2 million, was 8·6% less than in 1959–60 and of this £106 was spent on power stations, including £53 million on nuclear stations. A sum of £3·2 million was paid to the AEA for nuclear fuel.

• **Calder performance** Performance of production units at Calder Hall and Chapelcross had exceeded the most optimistic forecasts, Sir Roger Makins said recently. The AEA chairman was speaking as guest of honour at the annual dinner of the Institute of Fuel.

Oldbury tender The CEGB has sent a questionnaire to the Nuclear Power Group asking for more details of their tender for Oldbury Nuclear Power Station. So far, no other questionnaire has been issued. It will be recalled that TNPG submitted a design incorporating a concrete pressure vessel.

AEA team visits USSR

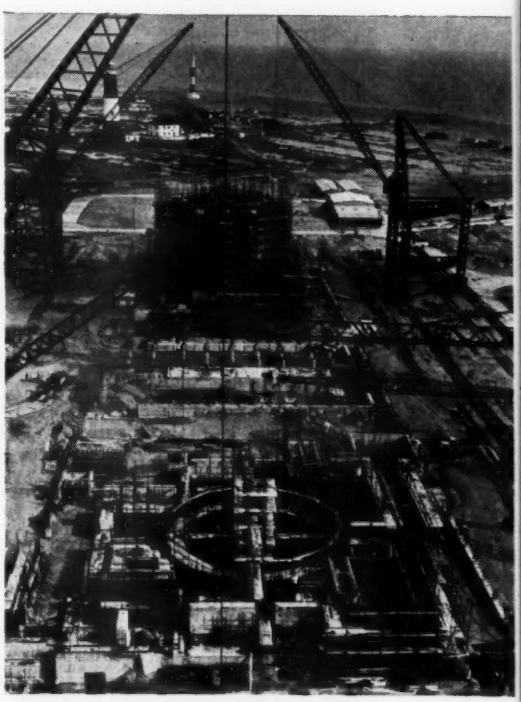
London Talks on reactor physics and experimental fast reactors have been held by an AEA team which visited the USSR from September 26 to October 10 The team was led by Sir William Cook, Member for Reactors. This is the second visit made under the recent UK-USSR co-operation agreement. A party of Soviet scientists visited Britain in July.

Visits were made by the eight-man AEA team to the Kurchatov Atomic Energy Institute, the sites of the Novo-Voronezh and Beloyarsk nuclear power stations and to Tbilisi where the party were guests of Georgian physicists.

The AEA team were: Sir William Cook; Mr P. Brock (Dounreay); Dr C. G. Campbell (Winfrith); Mr A. G. Frame (Risley); Mr D. C. G. Smith (Dounreay); Dr P. Murray (Harwell); Mr P. W. Mummery and Dr R. D. Smith (Winfrith).

• **EDF-3 started** Construction of the concrete pressure vessel for the third French nuclear power station has begun following the completion of successful tests. The design, a complete departure from Marcoule, will have the reactor vertical with a gas-tight liner about 1in thick inside the prestressed vessel.

• **AEA staff change** J. B. Cunningham, managing director of the AEA Engineering Group, is leaving the Authority to take a post with United Gas Industries Ltd. His successor is Mr H. V. Disney, at present deputy managing director. Mr Cunningham joins Sir Leonard Owen who has accepted an invitation to join the Board of United Gas Industries with effect from October 1.



DUNGENESS PROCEEDS Civil work continues to predominate on No 1 and 2 reactors at the 550MW Dungeness nuclear power station. The main feature of the above picture is the rising structure of No 1 reactor biological shield which is nearly 80% complete. Between the two reactors, foundations are being laid for the central change and control block.

WORLDVIEW

Euratom invites reactor proposals

Brussels More inclusive fuel guarantees are incorporated in the second Euratom invitation for proposals for the building of large-scale nuclear power plants for operation by December 31, 1965. The invitations were issued on September 21.

Previously, the fuel guarantees related mainly to water-cooled reactors and covered only the uranium dioxide fuel elements clad either in stainless steel or zirconium. The second invitation, in addition, provides guarantees for metallic uranium molybdenum-aluminium elements. This extends the coverage to types of elements which are expected to be proposed for organic-cooled power reactors.

Likely candidates, who will submit proposals before the closing date, June 1, 1962, are West Berlin's BEWAG group, the Netherlands SEP group, the Franco-Belgian SENA group and Germany's Stuttgart KBWP (the former AKS) group. For their proposals to be acceptable, there must be reasonable assurance that the plant can be brought into operation by December 31, 1965, and can thereafter be operated for 10 years as a source of safe and reliable power. Preference is to be given to proposals for plants having a capacity of at least 150 MW, though smaller plants will be considered if they present some special interest for the programme.

The invitation follows a trip by Euratom president, M. Hirsch, to Washington this summer where long-term guarantees of the availability of enriched uranium and the invitation were topics of discussion. The invitation has been delayed for over a year and one reason is said to be differences over the flexibility of the invitation's terms.

These apparently have been resolved, for in addition to better fuel element guarantees, the programme also assures, over a ten-year period, a market for plutonium recovered from the reactors. It also provides long-term assurance by the US that chemical reprocessing services will be available on the same terms as those offered to US reactor operators.

The assistance to be supplied by the US includes an agreement to sell or lease to the Community a net amount of *up to* 30,000 *kilogrammes of contained U*-235 for use in the joint programme at prices comparable to those offered US reactor operators. The current value of initial fuel loadings under the programme is estimated at approximately $100 million. The AEC is also authorized to buy back, over a ten-year operating period, *up to* 4100 *kilogrammes of plutonium* recovered from reactors at the prevailing US fuel value which at present is $12 per gramme. *Loans up to* $135 *million* will be available from the US Import-Export Bank, but the total credit for one project cannot exceed 40% of its total capital cost.

• **Fuel delivery** The first delivery of special nuclear fuel by the USAEC under the Euratom co-operation agreement was completed on September 20. Euratom received one kilo of plutonium of which 300 grammes are for Societe Belge Belgonucleaire and 700 grammes for the French Atomic Energy Commission.

• **Belfast reactor?** The possibility of buying a research reactor is to be studied by a Queen's University committee headed by Professor K. G. Edwards, nuclear adviser to the Government of Northern Ireland.

• **RCN annual report** The Netherlands Reactor Centre carried out a design study of a test reactor for the Euratom ORGEL project and also a low-power reactor design study for the Technological University, Eindhoven, says the RCN annual report for 1960.

Interatom project for a sodium-cooled reactor

Bonn An application has been made by Interatom to the German Atomics Ministry for financial aid in developing an advanced sodium-cooled reactor, *Nuclear Power* understands. The money would be used for a full-scale design study to discover the practicability of building such a reactor.

It is believed that the fuel proposed would be highly enriched uranium carbide and that zirconium hydride would be the moderator.

• **Marine insurance** Technical aspects of the insurance of hulls and cargoes, including nuclear risks, were fully discussed at the Conference of the International Union of Marine Insurance which met in Lisbon in September. About 700 delegates from 34 countries attended.

• **Austrian reactor order** The Austrian Society for the Expansion of Applications of Nuclear Energy has ordered a one kilowatt Siemens- Argonaut training reactor from Siemens-Schuckertwerke AG of Erlangen for Graz University.

Chooz PWR contract signed

Brussels A definitive contract for the 242 MW underground Franco-Belgian Chooz nuclear power plant, the largest under the Euratom construction programme, was awarded, as expected, to Westinghouse Electric International Co. of the US, Ateliers de Constructions Electriques de Charleroi of Belgium, and Framatome of France.

Signing of the detailed contract by Societe d'Energie Nucleaire Franco-Belge des Ardennes (SENA) with the three nation manufacturing group was witnessed by officials of Euratom, which last July allocated $8 million toward financing of the project at Chooz, France, near the Belgian border in the Ardennes region. A provisional agreement on the project was announced last year.

The project for a closed-cycle water reactor of Westinghouse design was accepted by the Council of Ministers of Euratom under the programme of investment in large plants for the six nation European community.

Italy studies mercury-cooled reactor

Rome A reactor cooled with mercury vapour is being considered by the Italian Committee for Nuclear Energy (CNEN). Plans are also being formulated for a study of 5 MWe power reactors for developing countries, says a CNEN outline of the future Italian nuclear programme.

The technical and economic design study of a mercury-cooled reactor for power reactors at high temperatures, will widen the scope of its programmes, says the CNEN. The cycle of mercury vapour steam has been used successfully in several thermo-electric stations in the USA and has very favourable heat transfer characteristics. These would be particularly attractive for high temperature reactors and for fast breeders. However, mercury has unfavourable nuclear characteristics though studies in the US have shown that these can be overcome.

A reactor study group is to set up at the Casaccia Centre of Nuclear Studies. This will provide experience of irradiation of reactor materials and proving fuel elements. The CNEN materials division will study production processes for primary material and the chemical reprocessing of irradiated fuel; it will also study fabrication techniques for prototype fuel elements for the PRO reactor (OMR) and for the ANGR reactor, a gas-cooled intermediate type.

This latter reactor has cylindrical fuel elements with a heat transfer surface on the inside and outside, enriched fuel will be used. It is claimed that the ANGR will have a power density three times that of conventional gas-cooled graphite moderated reactors.

Production of fuel elements similar to those used in the SENN and SIMEA reactors will also be studied.

All these activities will be gradually concentrated, from the beginning of 1962, at the Casaccia Centre where a computer department, using an IBM 1620 will be installed.

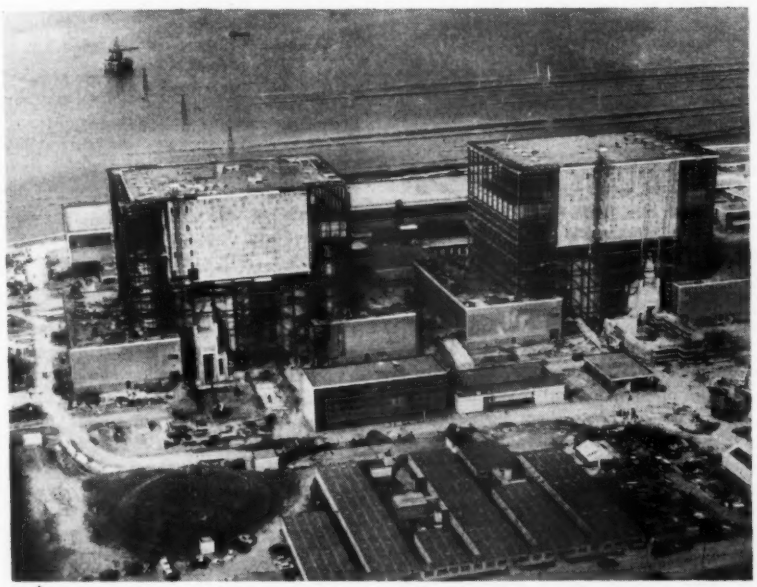
• **Hungarian cyclotron** An 800,000 volt cyclotron has been put into operation at the Debrecen Nuclear Research Institute in East Hungary.

• **German fast breeder** Design work on a fast breeder will start at the Karlsruhe Nuclear Research Centre when work on the research reactor, FR-2, is completed.

Core changes complete at Hinkley

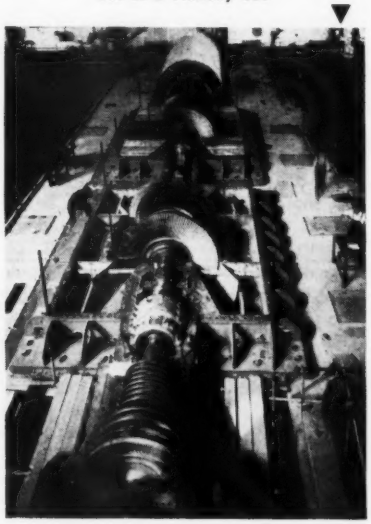
Fuel loading of the first reactor at Hinkley Point is now scheduled to begin on February 9, 1963 and that for the second reactor in July. Latest plans are that the station is expected to be commissioned early in 1964. This delay of about twelve months in completion has been due to changes in the graphite core that were made at the request of the CEGB after the tender had been submitted. Labour troubles have also contributed to the delay. Work on the £65 million station has progressed steadily with clean conditions established in No 1 reactor where graphite laying has started. Civil engineering works for the 500 MW English Electric/Babcock & Wilcox/Taylor Woodrow station are almost complete. In the first reactor building, plant is being installed to deal with loading of fuel and the instrumentation for the reactor. The boilers are being fitted prior to testing, early next year, of the circulators and main carbon dioxide gas circuit.

▲ The large insulators in the switching compound give a futuristic air to the station



▲ An aerial view of Hinkley Point showing the two reactor buildings and, offshore, the seawater intake

A lengthwise view of one of the six 93,500 kK main hydrogen-cooled turbo-alternator sets being assembled in the turbine hall at Hinkley. There will also be three 33,000 kW variable speed turbo-alternator sets of which one will act as a standby set



French also find beryllium difficult

Paris Difficulties over beryllium-clad fuel elements are apparently causing the French Atomic Energy Commission some concern. The annual report states that the natural uranium heavy water, gas-cooled reactors, EL-4, would be built but studies were still needed on uranium oxide, beryllium-clad fuel elements. It is feared that these will not be completed in time for the first fuel loading and stainless steel and slightly enriched uranium would then be used.

The report says that in the short run, the Commission will rely on the natural uranium, gas-cooled reactor. But it intends to develop the natural uranium, heavy water moderated reactor though its economic operation had not yet been conclusively proved. Higher burn-up fuel rates had to be achieved to offset investment, in the first of these stations which initially would be higher than that for graphite-moderated reactors.

Breeder reactors were a long term solution and a research prototype reactor, RAPSODIE, would come into operation in 1964. A more powerful facility might be built in the future.

Other points covered by the report include: **fuels**—an annual rate of 1600 tons of uranium metal was to be reached in 1962; **submarines**—building of the first reactor had started and first deliveries of enriched uranium had been received; **power**—by 1965, nuclear stations would produce 600 MW and by 1970, 1600 MW.

• **East German reactor** Construction of a zero energy reactor for physical and technical research has started at the Rossendorf Nuclear Research Centre near Dresden. The 10 kW reactor is expected to become operational in 1962.

• **OEEC ends** The 13-year old Organization for European Economic Co-operation (OEEC) ended on September 30. It was replaced by the Organization for Economic Co-operation and Development (OECD). The change of title reflects the fact that two non-European countries—the USA and Canada—are now full members.

Reactor for Greenland? Plans for a small nuclear power station near Godthaab in Greenland are currently under consideration, according to an official of the Greenland Affairs Department. No final decision will be taken until the autumn.

• **Cheaper gas** Sir Henry Jones, chairman of the Gas Council of Britain, predicted a continuing reduction in the costs of producing gas when he presented the annual report and accounts of the council for 1960-61.

WORLDVIEW

Fifth IAEA General Conference

Vienna Behind the dispute over the election of Dr S. Eklund of Sweden as the IAEA Director General, itself an echo of the East-West struggle at the United National General Assembly, came surprising news of cordial US-USSR meetings. These half-dozen meetings between Dr Glenn T. Seaborg, chairman of the USAEC and Professor V. S. Emelyanov of the USSR, covered possible joint action in building a £500 million high speed particle accelerator—the world's largest; an exchange of scientists and scientific reports (the latter has already started) and finally, disposal of radioactive waste.

But overshadowing the fifth regular session of the Agency's two-week General Conference was the debate and demonstrative walk-out by Professor Emelyanov when Dr Eklund was installed as Director General. (Late reports indicate that the Soviet Union was present at the first Board of Governors meeting after the Conference.) Basic reasons for the Soviet attitude were said to be because Dr Eklund had been selected to represent the 'Western' powers and was 'out of tune' with Asian and African needs.

A middle view was expressed by Dr H. J. Bhabha for India. He said he could not support a candidate opposed by the United States and in this case could not support one opposed by the USSR. He argued that the Director General should come from an area where social and economic conditions differed from those in the USA and Western Europe. It was not a question of introducing a formal vote into the proceedings but it was a fact that there were two opposing groups and a Director General should be supported both by the USA and the USSR. India would have no objections to a candidate from Western Europe at a later date after the post had been filled by someone from another area for the coming term.

The upshot of the debate was a formal vote which approved the appointment of Dr Eklund by 46 votes to 16 with six abstentions.

Safeguards Of note in the general debate was the forthright attack on the safeguards system by Professor Emelyanov. His reason was that the system deterred smaller countries from asking the Agency for the technical help it was meant to provide. Later, in fact, Professor Emelyanov made a point of stressing the absence of controls in the Indo-Soviet agreement signed at the end of the Conference.

Some support for this argument came from France. Dr Bertrand Goldschmidt pointed out that there would be hardly any demand for the supply of nuclear fuel for power reactors through the IAEA in the immediate future. France was, therefore, against too strict an application of the safeguards provisions; this too-strict application could encourage interested countries to look for their supplies bilaterally rather than through the Agency.

Reorganization The present structure of the Secretariat needed overhauling, Mr Sterling Cole, the retiring Director General, told the General Conference in his final address. 'The experience of almost four years has indeed shown the need for some readjustments,' Mr Cole stated. 'The present structure of the Secretariat results in a lack of consistency, a tendency to create avoidable administrative complications, and in particular, to produce areas of duplication and thereby a need for an exaggerated amount of internal co-ordination. In my opinion, the serious faults of the existing structure are hampering the efficiency of the Secretariat to an appreciable degree. In addition, a more efficient organization would result in economics in staff in some areas of work'.

Other points made by Mr Cole were: the need for a long-term programme for the Agency; the financing of such a programme; the relationship between the Board of Governors and the Director General which could be remedied by only having two Board meetings a year to deal with board policy including the Agency's annual programme and budget; and the 'vital' question of support for the Agency by member states. On this last item Mr Cole said it was not merely a question of finance; it depended on the extent to which the great power used the Agency as an instrument of scientific co-operation and also the extent to which it was used as a means of atomic aid by the advanced to the developing nations. He specially urged the major nuclear powers to provide the Agency with fissionable materials, pre-preferably at a discount, and trained personnel for its staff and technical assistance programmes.

Resolutions Among the resolutions passed by the General Conference were: a study of a plan to set up an international centre for theoretical physics; the desirability of establishing international demonstration nuclear power plants and of promoting the establishment of regional nuclear power projects; promoting international co-operation for the effective use of research reactors in member states; arrangements for training scientists from the developing areas at the Agency's laboratory at Seibersdorf and the preparation of a long-term programme for the Agency's activities and to present a progress report on this work at the next session of the General Conference.

The Conference also approved the Agency's budget of $6,261,000 for 1962.

Delegates at the Conference held in Hofburg, Vienna's former Imperial Palace, listen to Glenn T. Seaborg, USAEC chairman

• **Safeguard inspectors** Officials are to be appointed to the IAEA's new division of inspectors. Their work will be directed towards preventing diversion of IAEA assistance for warlike purposes and ensuring application of IAEA health and safety measures.

• **Yugoslavia's TRIGA** The IAEA has formally approved a request by Yugoslavia for assistance in acquiring a TRIGA research reactor.

Sir Roger Makins, chairman of the AEA, (left), Dr Bertrand Goldschmidt, governor from France on the IAEA Board of Governors, and Sterling Cole, IAEA Director General, in informal discussion during the fifth General Conference

Eurochemic may process US fuel

Paris Negotiations have started between the European Nuclear Energy Agency and the USA to determine conditions under which the Eurochemic plant can reprocess US irradiated fuel used in European reactors. This is stated in the Third Report on the activities of the ENEA.

The report covers the period January 1960-July 1961 and records the progress of ENEA's three joint undertakings: the Eurochemic Company for processing irradiated fuel and the Halden and Dragon reactor projects. New topics under discussion include a marine propulsion proposal and closer international scientific co-operation.

On the financial status of Eurochemic, the report says that more money is likely to be needed than originally estimated and negotiations have started with the participating countries to cover the increase in capital needed over the next few years.

The ENEA Steering Committee considered that a precise study of the economics of heavy water production in Iceland should be made. This should take into account not only the quantity and quality of geothermic steam available but also the relatively low American price for heavy water. (At the end of 1959, ENEA made an overall study of the possibilities of producing heavy water in Iceland). A meeting of ENEA experts will be held in October to examine the question and make proposals to the Steering Committee.

Other points covered by the report are:
Halden—Some thought is being given by the Norwegian Institute for Atomenergi to further modifications to the reactor to that a wide range of experiments on BWR systems may be carried out on a joint basis after 1962;
Dragon The reactor experiment is due to be completed on March 1, 1963 and the present agreement, concluded in 1959, ends in April 1964. Arrangements are being envisaged for extending the existing agreement.

Nuclear ships Reports comparing, from an economic viewpoint, current national studies and economic potential of nuclear ships together with objectives and technical characteristics of a joint nuclear ship project will be submitted to the Study Group on Nuclear Ship Propulsion in October.

Co-operation A group of experts is meeting in October to recommend to the Steering Committee its proposals for co-operation in nuclear research.

Nuclear data The European-American Nuclear Data Committee suggested the establishment of a centre for the development, fabrication and distribution of special foils and targets for the measurement of basic nuclear data, as well as the institution, in the field of reactor physics of a co-operation comparable to that existing in the area of measurement of nuclear cross-sections. These proposals are now being studied.

• **New metals use** Health risks which might arise from use of newer metals in industry are commented upon in the 1960 annual report on Industrial Health issued by HM Chief Inspector of Factories. The report refers to the increasing use of copper based on beryllium alloys and the action taken by inspectors to observe and advise on precautions to be taken against dust and fumes.

• **Latvian reactor critical** The 2 MW research reactor at the Salaspils research centre, Latvia, went critical on October 9. The centre will provide research facilities for scientists from Lativia, estonia and Lithuania.

• **Bulgarian reactor operates** The 2 MW Soviet-designed reactor at the Institute of Physics, Sofia, is now in operation.

• **Danish BWR study** A design study of a 210 MW nuclear power station with a dual cycle BWR has been completed by Danatom in collaboration with Danish authorities and power companies.

• **W. German ship order** The first West German nuclear powered ship, a 15,000 ton bulk carrier, is to be built by Kieler Howaldts werke AG. Construction of the vessel for GKS of Hamburg will start next year. Costs are estimated at more than 40 million D-marks.

SENN—Euratom contract

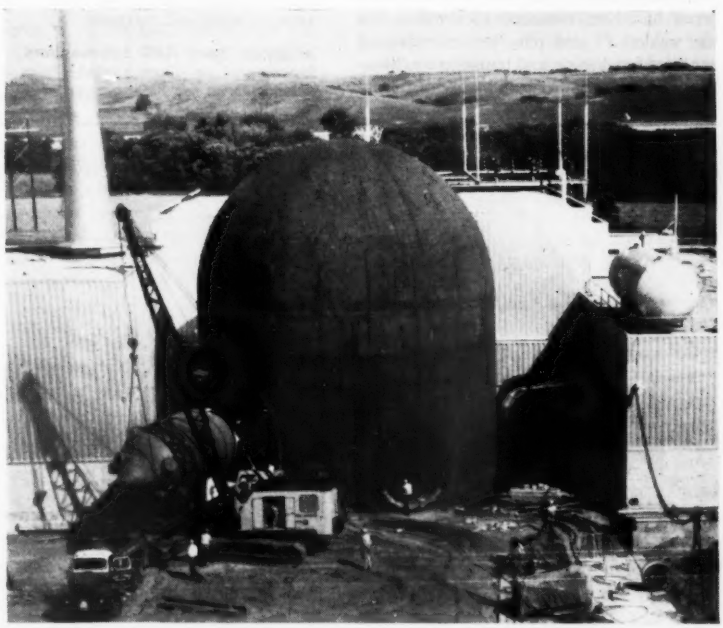
Brussels Contracts assuring the Societa Elettronucleare Nazionale (SENN) of fuel supply, reprocessing facilities and plutonium repurchase for its 150 MW boiling water reactor on the Garigliano River have been signed between the US, Euratom and SENN. The Italian company will supply Euratom and US with information on the plant.

The contracts also provide for US capital loan arrangements and fuel guarantees. However, since the guarantees on the first core by the manufacturer are understood to be more advantageous than those under the Euratom contract, SENN will benefit from the provision for ten year deferred payment for the reactor fuel. Capital financing for the project has been arranged t hrough the World Bank. (See p 59)

Merlin commissioned at Julich Research Centre

Bonn The 5 MWt British MERLIN research reactor at the Julich nuclear research centre was officially inaugurated on September 28 in the presence of Lord Hailsham Minister for Science, and Dr Franz Meyers, president of the State of North Rhine-Westphalia. So far development at the Institute includes completion of the Institute for Plasma Physics and near completion of the Institutes for Reactor Materials, for Reactor Fuel Elements and for Medicine.

A second reactor at the centre, a materials testing reactor (DIDO) is expected to go into operation next year. It costs about £2 million to build against £700,000 for a MERLIN, and has a maximum heat output of 12·5 MW.



PATHFINDER PRESSURE VESSEL Installing the pressure vessel for the 66MW Pathfinder BWR on the Big Sioux River, South Dakota, has brought the project to 85% completion. Pre-operational system tests of the Pathfinder plant, being built by Allis Chalmers for the Northern States Power Company, started in October. Initial criticality is scheduled for mid-1962

OVERSEAS

Tokai-Mura delayed eight months

Tokyo A delay of eight months in completing the 150 MW Tokai-Mura reactor has been announced by the Japan Atomic Power Company (JAPCO). The completion date is now March, 1965, instead of July, 1964.

According to the president of the company, Mr D. Yasukawa, several technical hitches had occurred. These included unforeseen troubles with the reactor design because of safety provisions particularly from earthquakes and also changes in steel and graphite.

JAPCO also announced that steel for the pressure vessel, to be made by Nippon Seikosho, was the subject of irradiation tests in one of the Calder Hall reactors. On graphite, the company stated that the change from British Grade A to the French company Péchiney's Quality One was because the French graphite had 1·5 times more tensile strength. Irradiation tests were being carried out at the Saclay research centre to further ascertain the physical and mechanical properties of this graphite. Specimens had been in a reactor since March.

Referring to fuel element tests in the Australian HIFAR reactor, the company announcement pointed out that sufficient proof had been obtained to confirm that the welded Zr end plug would withstand expected irradiation and temperature. Similar confirmation was to be obtained from experiments in Calder Hall reactors. HIFAR tests also indicated that at about 3500 MWD/t irradiation and at 4–500°C, swelling of the hollow fuel elements was about the same as for rod fuel elements. During tests, some of the specimen temperatures were raised to as much as 700°C due to failure in the rig temperature control and minor cracking and deformation had been observed.

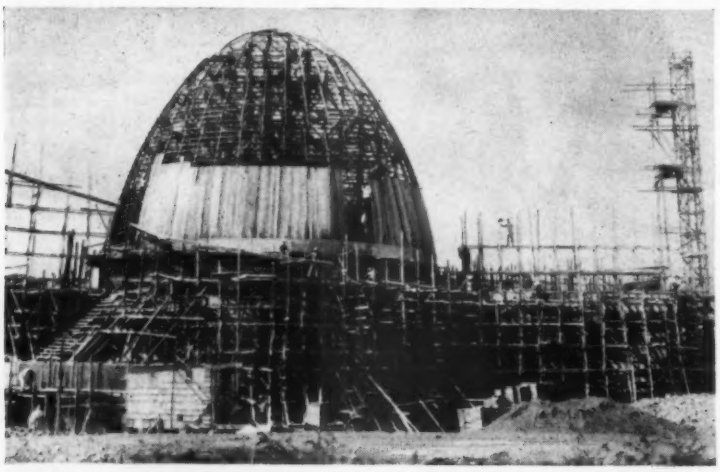
Germans survey Perut

Bonn Three West German geologists, seconded by the Ministry for Atomic Energy to the Peruvian authorities last April, have returned to Germany on completion of their work in Peru.

In the Vilcabamba area of Peru they discovered a deposit with uranium mineralisation and mapped it with scintillation equipment, following which 1400 samples were taken and a number of boreholes sunk. Further examination of the samples is to take place in Germany and when this supplementary work has been completed, details of the deposit will be released.

• **Brazil-Paraguay agreement** An agreement covering co-operation in the peaceful use of atomic energy has been concluded between Brazil and Paraguay.

• **Japan bans US submarines** Japan has refused to allow United States nuclear submarines to use Japanese ports.



PHILIPPINE REACTOR When installed, the 1MW research reactor being built for the Philippine Atomic Energy Commission in Quezon City, 11 miles from Manila, will be over 9 ft below ground level. This picture shows the building which is nearly 65% completed. The reactor, built and fabricated by GE of the US, is expected to go critical about the middle of 1962. It is light-water cooled and moderated, graphite-reflected and fuelled with enriched uranium

• **Russian nuclear submarines** Modern nuclear submarines equipped with rockets of various types now formed the basis of the Soviet Navy, Marshall Grechko, commander of the Warsaw pact forces, said on July 30, the occasion of Soviet Navy Day.

• **Iraqi progress** An IAEA expert is advising the Iraqi Government on the setting up of a research reactor and associated laboratories at the University of Teheran's nuclear centre.

• **Indian heavy water plant** India's heavy water plant at Nangal is scheduled to start production by December. It is designed to produce 14·5 tons annually.

• **Canadian—UK uranium talks** A 'stretch-out' in the talks on the sale of 12,000 tons of Canadian uranium to Britain is reported from Canada. These have been delayed a month and are expected to resume in mid-November.

• **Egyptian reactor at power** The 2 MW reactor at Inchass, near Cairo, reached full power in the week ending October 7.

• **Brookhaven accelerator** The Alternating Gradient Synchrotron at the US Brookhaven National Laboratory has been inaugurated. Said to be the largest and most powerful particle accelerator in the world, the AGS cost about $32 million and is capable of delivering a peak energy of 33,000 MeV.

• **Nuclear indemnity** A bill to extend the coverage of the indemnity provisions of the 1954 US Atomic Energy Act so as to cover nuclear incidents happening outside the USA has been introduced into the House of Representatives.

• **Australian uranium** United Uranium N.L. has completed shipment of its 1961 delivery quota of uranium oxide under the UK Atomic Energy Authority contract. The company is proceeding with production of the 1962 quota.

UK may supply Pakistan with reactors

London The possibility that the United Kingdom will supply Pakistan with power and research reactors is mentioned in a recent announcement by the Atomic Energy Authority. This says that the AEA and the Pakistan AEC will develop their collaboration in the nuclear field. Sir Roger Makins and Dr I. H. Usmani, chairman of the Pakistan AEC, have exchanged letters defining their mutual interests. In addition to present exchanges of reports and training, there are now to be staff consultations as well as assistance and advice on radioisotope uses, particularly new uses of interest to Pakistan. The eventual supply of nuclear research and power reactors to Pakistan is also envisaged.

The possible supply of power reactors presumably relates to the project for a 50-100 MW reactor to be built near Karachi. Dr Usmani stated after the IAEA Conference that Pakistan would ask the IAEA for advice on this plan. (A report on nuclear power prospects in Pakistan carried out by a US firm is to be submitted to the Agency for review). Technical assistance would also be asked for from the United States and finance from the World Bank.

INDIAN POINT NEARLY COMPLETE In the last stages of construction is the 275MW PWR (112MW from an oil-fired superheater) being built by Consolidated Edison Company on the east bank of the Hudson River. Preparations for receiving fuel at this Indian Point plant are under way and it is hoped that the plant will be completed, an operating license issued, and criticality achieved, before the end of 1961

SENN reactor shipping date changed

Washington A 18-month change in the completing shipping date for the export of the 150 MWe boiling water reactor to SENN in Rome has been asked for by the International General Electric Company of New York. It asks the AEC to change the date from Jan. 1964, to Aug. 31, 1965.

The company asks for the amendment to its export license because of changes which have taken place since the original application. Included among the revisions is that the total dollar value of the equipment to be exported is now $8,500,000 instead of $21,360,000. Changes are also sought in the specifications of the first core loading which are now: 208 fuel assemblies, each with 81 fuel rods; 69 of the rods will have enrichment of 2·1% (approx.) and 12 of the fuel rods are enriched to 1·6% approx. Total weight of the U-235 is estimated at 990 kg.

The SENN plant design is similar to that of the 180 MW Dresden nuclear power station. One advantage in the design is the possibility of a sizeable increase in the power rating. GE of the US are designing and sizing components of the steam supply system to enable a 50% increase in the power output at a later date. After the station is operating, SENN is to conduct a review to determine the feasibility of installing an additional 80 MW turbine when more power is needed in the area. Additional steam to run this unit would come from using fuels of higher power density than those planned for the first core loading.

AEC surveys reactor operations

Washington Surveys of reactor operations are being made by the AEC's Division of Licensing and Regulation. Data are being sought on the use of boron carbide powder in the control rods of some reactors, on the anticipated radiation exposure of reactor pressure vessels, and on gaseous effluent monitoring and control practices presently being followed in licensed reactors.

The AEC says that recently there were some instances where control rods containing boron carbide powder swelled significantly beyond their original dimensions during reactor operation, In at least one case, the swelling was severe enough to cause the control rod to jam in its guide. Although this case presented no immediate hazard to health and safety and the situation has been corrected, the AEC believes it is necessary to obtain up-to-date information on other reactors in which boron carbide powder is used in the rods which control the nuclear reaction. The Commission is seeking data on how well control rods are performing and the adequacy of procedures used to determine the occurrences of swelling or other indications of possible trouble.

Russians sign breeder agreement with India

Vienna Joint research on breeder reactors is covered in the agreement on scientific and technical co-operation in the nuclear field signed here between India and the Soviet Union. This is the first Soviet agreement with another country in which research with breeder reactors has been included.

The agreement does not mention safeguards and provides for joint research on natural uranium reactors, breeders, and research on the thorium-uranium-233 cycle. The Soviet Union will, in addition, supply India with small amounts of natural and enriched uranium, uranium-233 and plutonium for research purposes. Facilities will be provided for training Indian scientists and aid will be given for prospecting and mining of uranium.

Nuclear rocket test date

Washington The flight test of the nuclear rocket (NERVA) is now 1966–67, the Subcommittee on Research, Development and Radiation of the Joint Committee on Atomic Energy was told recently. The disclosure came during a two-day hearing on the nuclear rocket programme (Project ROVER), the SNAP programme and the nuclear ramjet programme (Project PLUTO). Generally, the Committee took a critical view of progress but felt that an increase in effort was now being made.

Commissioner R. E. Wilson, AEC, indicated that the next power operation of TORY IIA-1, a reactor built under the PLUTO programme would be conducted late in September or in early October. Another reactor, TORY IIC was being built; this was the first reactor specifically designed to test nuclear ramjet requirements.

Japanese nuclear plans

Tokyo Implementing the proposed long-range nuclear development programme is a difficulty that has to be overcome says the Fifth Annual Report of the Japanese Atomic Energy Commission. Funds needed for the ten year programme to 1970 (1000 MW) would be in the region of 200,000 million yen. It is envisaged, too, that in the following ten year period a total of 7000–9000 MW will be installed.

On nuclear ship propulsion, the report says that efforts will be directed towards building the nation's first nuclear powered ship by 1975. Meanwhile, the Japan Atomic Energy Research Institute (JAERI) had plans to build a swimming pool type reactor for shielding studies. (Co-operation is also envisaged with GKSS of Hamburg).

In 1960, two research reactors at the JAERI were in operation and eight other reactors were being built. This total included four university research reactors, the Tokai-Mura plant; JRR-3 (the first reactor built by Japanese firms) and the Japan Power Demonstration Reactor at JAERI.

WORLDVIEW

Savannah fuel loading delayed

Washington Up to six months delay is unofficially reported with the NS *Savannah*. Chief difficulty has been the failure of the reactor control rod drive system to perform up to specifications, says Richard P. Godwin, head of the Maritime-AEC Joint Group and Director of the Savannah project.

On July 24, the AEC authorized fuelling, start-up and operation of the *Savannah*'s reactor for test and demonstration purposes. It was hoped to load fuel within a few weeks of that time but careful tests disclosed conditions which made it necessary *to postpone actual fuel loading*.

According to Mr Godwin, the difficulty encountered with the hydraulic portion of the control rod drive system has now been adjusted and 'we have reason to believe that the system is working adequately and performing completely up to the specifications demanded of it. The final reactor tests currently under way are confirming these expectations'.

Construction of the *Savannah* was completed on May 1, 1961. The vessel incorporates a 74 MWt pressurized water reactor built by The Babcock & Wilcox Company of New York. At present, final integrated systems tests of the reactor before fuel loading are underway. These include full scale tests of the cooling, control purification, radiation monitoring, emergency shut-down and all other systems associated with the reactor.

Once these tests are completed and faults, if any, remedied, a ten-day to two-week period of preparation will precede fuel loading.

• **Computer control of nuclear ships** 'Automating' the nuclear propulsion system of a 44,000 ton tanker would save $500,000-$750,000 over the 20-year operating life of the vessel, R. B. Rice, of the US General Electric told a recent meeting of the American Institute of Electrical Engineers.

• **Nautilus inquiry** An inquiry into possible sabotage abroard the nuclear-powered submarine *Nautilus* two years ago had developed no basis for prosecution, reports the US Justice Department. Damaged electrical cables were found in 1959.

• **Fuel shipment procedures** The USAEC has proposed procedures and criteria to be followed by licensees when shipping spent fuel elements. They apply to solid irradiation fuel elements containing 2000 or more curies of radioactivity in a single shipping container. Control will be exercised over cask design and shipping procedures.

• **Centrifuge development** A research project aimed at developing an advanced gas centrifuge for isotope separation is to be carried out by the Garrett Corporation for the USAEC.

Uranium glut to end?

New York Civil demand for uranium ore for nuclear power generation in 1975 could exceed the present total annual production, according to a US General Electric executive. Less than 5% of the present mined total of eight million tons annually was used in electric power production, Dr L. R. Fink, general manager of GE's Atomic Products Division, told the recent American Mining Congress.

He pointed out that nuclear fuel now represented about 25–30% of the cost of nuclear power. Economic improvements still required could not be achieved only through technical advances in technology. The cost of uranium had to come down to encourage expansion of the nuclear power market.

A 15% (one mill—0·091d—per kWh) cut in the cost of nuclear-electric power in the next few years could mean the difference between ten million and thirty million kilowatts of installed nuclear generating capacity by 1975.

FUEL FOR BR-3 Technicians at Westinghouse Electric Corporation's Atomic Power Department secure a fuel element for Belgium's 11·5MW BR-3 reactor at Mol. Each element is packed in a hermetically sealed container and 40 were shipped from New York on September 15. Shipment of the core for BR-3 was delayed more than six months. The reason was a need for Belgian legislation to indemnify suppliers of reactor components against liability from third party claims in event of nuclear accidents

Fuel ordered for Puerto Rican reactor

Washington Two contracts for fuel for the Boiling Nuclear Superheater (BONUS) Power Station under construction in Puerto Rico have been awarded by the AEC to Combustion Engineering Inc. of Connecticut. This award brings the completion of the plant a stage nearer. Work started in September, 1960, and the plant is expected to be operating in December, 1962.

The 16·3 MW BONUS plant is being built as a joint venture between the AEC and the Puerto Rico Water Resources Authority. Its main purpose is to demonstrate expected benefits from using water reactors producing superheated (dry) steam in nuclear power plants.

The contracts awarded to Combustion Engineering were for $488,200 for 36 fuel assemblies for the superheater section and for $411,950 for 74 fuel assemblies for the boiler zone. Delivery is to be completed within about 11 months.

• **Enriched uranium** The amount of US enriched uranium to be made available for domestic and export use, announced recently by President Kennedy, will total 165,000 kilogrammes against 100,000 kilogrammes released in 1957.

• **Allis Chalmers wage cuts** Pay cuts of 5% to 25% for its 18,000 salaried employees have been announced by the Allis-Chalmers Manufacturing Company. The cut, the company says, is a stopgap measure to increase profit margins.

AEC builds second Polar plant

Washington A second nuclear power plant is to be built in the Antarctic by the AEC. The plant, PL-3 (Portable Low Power Reactor No. 3), will be operated by the U.S. Navy after a testing programme by the AEC. It is the second of the power reactors authorized for the South Polar regions with the AEC currently producing a nuclear power plant for operation at McMurdo Sound in 1962.

The PL-3 will be used to provide electric power and steam for the station, and will also produce steam to operate snow melting equipment designed to provide an ample supply of fresh water at the site.

The invitation to bid on the plant was issued by the AEC last May, and called for a power plant capable of generating 1000 kWe net and 1·5 million BTUs per hour in the form of steam. The plant is to be assembled in modules suitable for transport in a C-130 cargo plane from McMurdo Sound to the inland site. Shipment to McMurdo Sound, by ocean transport, is scheduled for late 1963, with the plant expected to be in operation in March, 1964. A light water-cooled and moderated reactor of either the forced circulation, pressurized water type or the natural circulation, boiling water type, fuelled with enriched uranium, will power the plant. It will be designed for a two-year life.

Cross Section by GRACCHUS

A BOMBING RANGE situated next to a nuclear power station and a nuclear research institute would be a source of dismay to anyone. This is, in fact, the case in Japan where the somewhat obsessional attitude to nuclear safety quite understandably shown in some quarters appears not to have been reflected by the siting of the Japanese Atomic Energy Research Institute and the Tokai-Mura Calder type reactor. Both are next to the Mito practice bombing range used by US forces stationed in Japan. After some dummy bombs had dropped within several kilometres of the Institute, the American authorities agreed to suspend 'drops'. However, I believe that practice has now be resumed. For the record, it has been stated that over the past eight years, there have been more than three hundred 'mis-drops' which involved nearly two hundred accidents and some deaths. This attitude is in decided contrast with that shown by the Minister of Housing and Local Government. Around Bradwell nuclear power station, for instance, three zones have been created within a radius of five miles of the station. These are a pink zone, nearest the station, in which all building and development plans have to be submitted to Whitehall for approval; a blue middle zone where restrictions exist on development affecting 50 or more people and an outer white zone where restrictions exist on development involving 500 or more people. With these restrictions, there must be little hope for siting nuclear stations nearer towns.

I SHOULD IMAGINE THE INDIANS must have noticed with particular interest the recent agreement concluded by the AEA for the supply of 400 tonnes of fuel for the Latina station. The price, said by the Italians to be £5·5 million, indicates a drop of some £3000 per ton in previously quoted prices of some £17,500. On this agreement, I hear that little mention has so far been made of a plutonium buy-back price but that the name Eurochemic has cropped up in talks.

A CONTRACT IS SOON to be placed with AEI by the Admiralty for transferring Hawker Siddeley's JASON research reactor to the Royal Naval College, Greenwich. I expect to hear that AEI will complete the dismantling of the reactor, refurbish some of the equipment and reassemble the reactor at the College. This work should be completed by the middle of next year and June, 1962 should see JASON in operation again. This sale by Hawker Siddeley brings to a successful end, two years of negotiation by the College for its site has already been approved on technical grounds. One stumbling block may be the question of fuel for the reactor. No decision has yet been reached and it remains to be seen whether the College will use the existing fuel or negotiate terms with the AEA for a fresh supply. Training of submarine crews will be one use for JASON and I expect that applied research and training of naval design staff will also be on the programme. Whether time will be available for other universities to carry out research is something that also remains to be settled.

AFTER ALL THE FUSS that was made at the IAEA General Conference, it turns out that the Soviet Union was represented at the first meeting of the Board of Governors held on the Monday after the Conference ended. Difficulties still remain ahead for the IAEA if the Russians intend to 'freeze-out' Dr Eklund who from all accounts showed signs of strain after his election. Of equal interest, perhaps, was the attack by the Soviet delegation on the safeguards system coupled with the comparatively sudden signing of an Indian-Soviet agreement which, it was pointed out, did not make any mention of controls. One waits to see what will happen with the Tarapur tender and the application of the safeguards system there.

SOME SMALL SOLACE for anyone concerned over fallout is the view that a nation engaged in nuclear tests in the atmosphere might possibly be sued by another nation for damages suffered by the latter's citizens. This suggestion comes from the American professor Samuel Estep, co-author of the book 'Atoms and Law'. However, he points out that any legal action for damages caused by radiation, for example a case of leukaemia, must be able to identify the specific radioactive source for that illness. So far no practical means exists for such identification. But some possibility exists for working out a statistically accurate system with which a nation might recover damages though this would not be a sure answer to the complex legal questions involving fallout. Professor Estep also notes that none of the nuclear powers has ever publicly taken a position on liability to those who may suffer as a result of nuclear tests.

What people in the Far East will think about this now that experiments indicate that rice grown in flooded areas tends to concentrate more Sr-90 and Cs-137 than upland rice would be interesting to record. These experiments, incidentally, have shown that the presence of ammonium in the soil increases the uptake of Cs-137 (an ammonium salt is the most common form of nitrogeneous fertilizer for rice).

A RECENT VISIT TO INDIA by two Central Electricity Generating Board nuclear experts to advise on tenders for the 300MW Tarapur station has, I believe, set a precedent. It is the first time the Board has acted in an advisory capacity for an overseas nuclear power project. The result may well be requests from other nations should British firms tender for stations abroad. Apparently the CEGB did not receive consultancy fees for the service. The Board was asked by the Indian Atomic Energy Commission to send some of their staff over to help with evaluating the tenders and complied with the request. Though it is interesting to note that Sir Christopher Hinton and Dr Bhabha are old friends, the motive behind the Indian move was their determination to save foreign currency. I believe the French have expressed criticism.

Arising out of the Indian tender is the poser that was put to me recently. Was a polite pressure reminder sent to some firms who might have taken part in the Tarapur tender saying that domestic stations were more important?

I hear that . . .

. . . **a sum of £200 million** has been proposed by the AEA for development of the Steam Generating Heavy Water Reactor and that access agreements are being negotiated.

. . . **an Italian firm** has been working on a advanced gas cooled reactor design in colla boration with a British group and has placed the project before Euratom.

. . . **another senior executive** is due to leave the AEA, probably to take up a post with Cornell University.

. . . **an AEA team** had their week-end upset when they were called upon to check a Swedish vessel for radioactivity after the shipping agents had said they thought the ship might have been in vicinity of the Soviet bomb tests.

. . . **the recently-approved graphite** licensing agreement between Nippon Electrode Company and the GEC has caused other Japanese graphite manufacturers to look closely at production and prices.

RESEARCH AND DEVELOPMENT

Modifications to Dresden

Commonwealth Edison's request to operate the 184 MW Dresden reactor at high void content will not be granted till further evidence is submitted of the analysis used to predict stability in the proposed tests. Other information has also been asked for by the AEC, who say that the tests, in which the void content was to be increased from 12 wt-% to 30 wt-% in gradual steps, involve hazards greater than those analyzed in the Hazards Summary Report.

The Company also propose to increase the primary and secondary steam flows. The turbine efficiency increases with higher primary/secondary steam flow ratios. In addition, an increase of secondary steam flow allows easier load pick-up and fixed control rod patterns can be maintained as the reactivity decreases with burnup. Extension of secondary steam flow limit will increase the core life, it is reported. There will be no need, therefore, to derate the core in order to remain within current license limitations.

Changes are also proposed for the reactor's hydraulic control blade drive system. The original boron-stainless blades had a slow setting time. The new boron carbide blades, being lighter, increase the operational difficulties. This will be overcome by adding a vent line from below the driving piston to the reactor. It will operate for a brief period after a withdrawal or insertion signal giving a faster setting time.

Superconducting material in production

Two American firms report the successful development of materials suitable for superconducting magnets. These magnets operate at near absolute zero temperature with virtually no power dissipation. A superconducting magnet weighing a few pounds and running from a 6V battery will give fields comparable from an electromagnet weighing tens of tons and requiring hundreds of kilowatts to run it. Difficulties hitherto have been finding a material whose superconducting properties are not destroyed by strong magnetic fields and are easy to work metallurgically.

At Westinghouse a magnet has been built containing half a mile of 10 mil wire. The wire is a niobium-zirconium base alloy of these two superconducting metals. Special techniques have been developed to process the material which is extremely brittle. A magnetic field strength of 43,000 gauss is obtained with a current of 20A; this represents a current density of 200,000 A/cm^2.

Scientists of the Radio Corporation of America have developed a mass-production technique. This is a simple chemical method for rapid and continuous growth of crystalline niobium-tin. The material is used as a coating for very fine wire. Tests on short wire lengths show that it remains superconductive in fields of 94,000 gauss with a 7A current flowing, giving a current density in the coating of 100,000 A/cm^2.

Bradwell control rods to be modified

As a result of computer studies on flux distribution it has been decided that it would be better to have a well-distributed absorber and so spread the flux more evenly in large gas-cooled reactors. This, we understand, does not represent a radical design change and will be easily accomodated. It is reported that both Bradwell reactors will be modified. The number of control rods will be increased from nine to twenty eight by replacing each 'black' rod by three 'grey' rods in each of the eight sector control zones and by four in the central zone.

• **Rotating reactor system** US Patent 2,968,602 covers a power generator that takes the form of a flywheel with four reactors positioned about its rim. The steam produced is tangential to the flywheel and gives it the rotary power.

• **Magnesium corrosion** Corrosion of magnesium alloys by superheated water is possible by adding about 0·7 ppm of sodium fluoride and then maintaining the pH at between 6 and 7 by periodical additions of HF. US Patent 2,970,885 describes the method.

• **Thorium/uranium fuel for 'Suspop'** A pilot plant at Reactor Centrum Nederland is producing five micron diameter spherules of ThO_2/UO_2 (80%/20%). These are for use as a fuel slurry in the two sub-critical assemblies under study.

• **Welding tantalum** Special methods of fusion welding tantalum in an argon atmosphere are being developed by Shell engineers. Though rare and expensive its corrosion properties make it ideal as a liner for chemical reactors handling highly corrosive liquids. Difficulties to be overcome are the low melting point, 5425°F, and the method of attachment to steel.

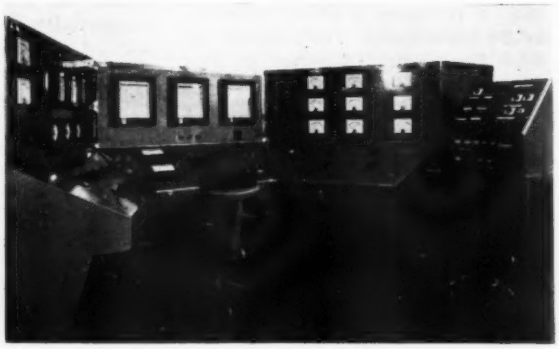
• **Ammonia fuel cell** Allis-Chalmers report laboratory work on a fuel cell using porous carbon electrodes (with platinum black as catalyst), and an electrolyte of concentrated potassium hydroxide. Ammonia is fed to the anode side and oxygen to the cathode. Work so far has been at low temperatures and pressures. Larger cells will be built going to higher temperatures to increase cell output.

• **Steam generator** US Patent 2,975,770 covers a steam generator capable of producing superheated steam entirely from nuclear reactor heat. It consists of a novel three-sided heat exchanger with heated alkali metal on the shell side and two banks of tubes.

• **Liquid hydrogen cross-sections** Evaluation of the neutron absorption scattering cross-section of hydrogen at liquid hydrogen temperatures is the object of a research contract awarded to Astra Inc., of the North Carolina Research Triangle, by the NASA. This information is needed for the nuclear rocket programme though the data would also be useful for deciding if liquid hydrogen could be used as a reflector for reactors.

Enrichment for Magnox reactors?

Slight enrichment for some fuel elements rather than a reduction of the average fuel irradiation would be a cheaper method of overcoming the problem of insufficient reactivity at any point in the fuel cycle. This is one conclusion drawn from a study of fuel cycles for magnox reactors (see this issue p. 79). Also, the authors say, that in the neighbourhood of 3–4000 MWd/t irradiation it would be cheaper to allow the fuel endurance limit to govern the maximum burnup rather than available reactivity, and to provide any required increment of reactivity by enrichment.



NEW CALDER HALL SIMULATOR The control desk of the three-zone nuclear power station simulator which is now being installed at the Calder Operations School. Designed by Short Bros. & Harland, the simulator has 200 operational amplifiers. The work of the Calder Operations School is described on p 88 this issue.

Concrete pressure vessel design in Czechoslovakia

No need for containment vessels is foreseen in Czech reactor design with pressure vessels made in reinforced concrete. Economic aspects of this type of design are being studied as well as the problem of gas sealing with an inner liner. Work is being carried out on various methods of prestressing.

(R. Servit. Czech Technical University, Prague. Czech Technical Digest (SNTL) Vol. 3, April, 1961, pp 28-33. Available from CEBG library, Bankside)

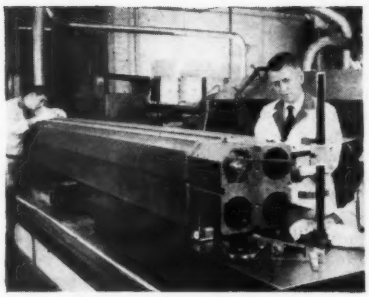
Graphite for the EGCR

Graphite columns for the 15 ft high, 10 in dia. core of the Experimental Gas Cooled Reactor, EGCR, have been delivered to the AEC at Oak Ridge. The 25 MWe helium-cooled reactor, designed by Allis-Chalmers, has 120 of these columns—said to be the longest pieces of nuclear graphite ever manufactured. The material was supplied by National Carbon Co., a division of the Union Carbide Corporation, who also did the machining.

Drilling tool being located for boring one one of the 5·25 in fuel element holes. The core from the first hole drilling can be seen still in the hole. Under the terms of the AEC contract, National Carbon has to identify and store all core material

Pre-machined columns were about 20 ft long, 17½ in square and weighed about 4400 lb each ; weights of finished columns ranged from 2250 to 3600 lb, depending on the amount of machining. Purity specifications called for total ash contents of less than 0·1% and a maximum boron content of 0·8 p.p.m. The density and strength were also closely specified as well as the nuclear purity. Cores from boring operations were machined to slabs and tested in the Hanford Test Reactor; this concerned measuring the reactor time constant in comparison with a test slab.

The machining had to be carried out to extremely close tolerances. These were checked by 100% dimensional inspection. Altogether, 234 holes were bored for the 30 in long fuel assemblies; these holes were 5·25 in dia., the tolerance 0·030 in, and hole location at both ends had to be within 0·010 in with the total allowable drift of the hole centreline from true of 0·093 in. The top of each channel hole has a counter bore and bayonet socket for the gas seal. Other operations included machining



Some of the 100% dimensional checks being carried out on a finished column. The shoulder for locating in the top plate and the machined fitting for the gas seals can be seen

grooves at corners and faces to provide holes in the finished assembly for experiments, control rods and flux scanners. Each column also had a hole at the bottom and a shoulder at the top for keying on to the top and bottom plates.

All these operations were carried out under clean conditions in polythene shielded areas. As well as dimensional checks, third point beam loading tests were carried out on all four sides of finished columns. Special care was taken in packing the columns to ensure that no damage occurred during transit and to prevent contamination.

• More experiments with polarized protons A device has been installed on the 50 MeV proton linear accelerator at the Rutherford High Energy Laboratory which can give a beam of protons 32% polarized. Hydrogen atoms are passed through a non-uniform magnetic field which separates out atoms with negative magnetic moment. These are bombarded with electrons and the resulting protons are extracted and fed into the accelerator.

New method of extrusion

The National Engineering Laboratory's annual report, recently published, gives details of a new method of extrusion. The die used in this process forms one end of a high-pressure chamber. A ram at the other end provides hydrostatic pressure, via liquid in the chamber, forcing a billet through the die. There is thus no direct contact between ram and billet. The method is said to give more uniform mechanical properties and requires lower pressures than conventional methods. The nosing of the billet to fit the conical entry die reduces the amount of work expended in deforming the metal, and the hydrostatic fluid acts as an efficient lubricant. Work, at present carried out on aluminium and an aluminium alloy, will be extended to the cold extrusion of high strength materials, especially steels.

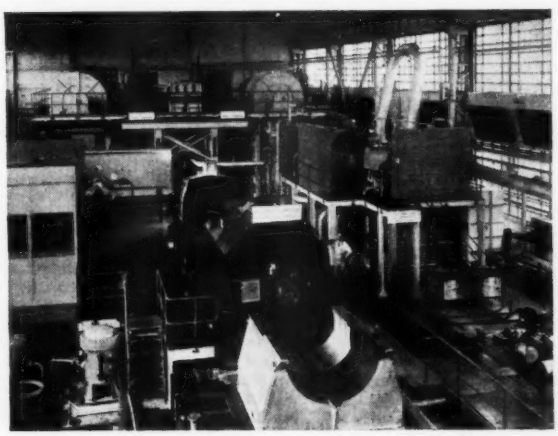
(National Engineering Laboratory. Annual Report 1960. HMSO 5/-)

Mechanical Engineering Laboratory for C. A. Parsons

A newly commissioned, engineering laboratory provides complementary facilities to the Parsons Nuclear Research Centre on the conventional side. The advent of nuclear power and increase in generating plant size led to the need for extension of testing and research facilities on turbines and on axial and centrifugal compressors.

The building, at the Heaton Works, Newcastle upon Tyne, is 250 ft long by 65 ft wide. In it is housed a 10,000 hp closed circuit compressor and circulator test rig. Compressors of up to 2000 ft³/s capacity can be tested at pressures of 300 lbf/in²g and temperatures of 300°C. The design ensures a low overall pressure dro , essential for testing compressors. Blading for compressors and alternator fans can be tested on a 180 hp circulator test rig. This will normally be used on open circuit though, if required, it can work at up to two atmospheres on closed circuit. Other work on blading phenomena will be carried out in a variable density air turbine. It will provide for tests over a range of Reynold's numbers and velocity ratios. Low pressure turbine blading and associated problems will be examined in a scale model L.P. steam turbine.

Other rigs will be used for tests on model exhaust ends and large exhaust blading, and a low speed wind tunnel will be used for exploring losses and pressure distributions.

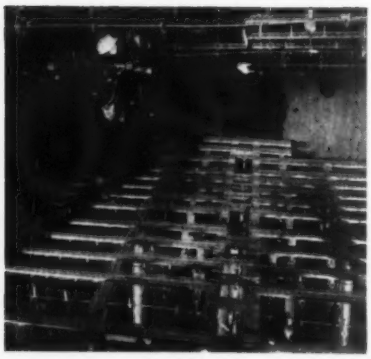


General view of the Parsons mechanical engineering laboratory. The drive for the 10,000 hp circulator test rig can be seen in the centre. On the platform at the back are the two 5 MW turbogenerators which supply power of varying frequencies to the laboratory

Stress relieving at Hunterston

Each of the 70 ft. dia. pressure vessels at Hunterston weighs about 1800 tons and the mean height is 85 ft above sea level. The first of these vessels has now been stress relieved together with the inner heat shield, core support grid, sections of the ducting and the standpipe penetrations for fuelling machine and control rods.

Radiant heaters were used to provide the uniform heating necessary, the system being designed by the Industrial Advisory Service, South of Scotland Electricity Board. A series of freely radiating Brightray strips was built up into a curtain-like structure between the pressure vessel and the cylindrical heat shield. Other strips heated the top and bottom crowns, following the curvature of the vessel; enclosed tubular heaters were used for the gas ducts. The whole of this fabricated structure was divided into 40 heating zones. Temperatures were measured at some 400 points including the pressure vessel skirt, along the gas duct stubs, the heater strips themselves and parts of the concrete biological shield. Measurements of differential temperatures in the irregular-sectioned forgings at duct roots and of the difference in temperature between top and bottom crowns were taken. On the assumption that the heating would be symmetrical, strip recorders were connected to thermocouples in one quadrant only with check readings from a few positions in the rest of the vessel.



Installing strip heaters under the core support grid

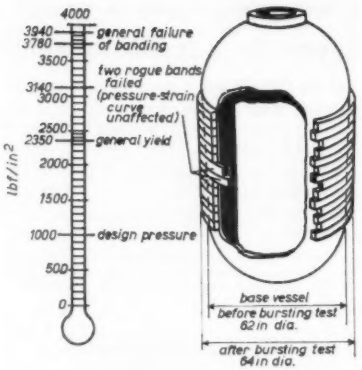
Two recording systems were used. About a hundred thermocouples connected to the strip-recorders mentioned and the rest (300) to a digital typewriter recording system. Readings from the strip recorders were plotted on a peg board. A plug placed in a thermocouple position on this board lit a lamp on models of the pressure vessel and heat shield corresponding to the actual position of the thermocouple. Thus if there were any temperatures differing from the mean, their position was immediately identifiable. Remedial action could then be taken by altering the input to one of the heating zones. The differential temperature readings were displayed on another strip recorder.

The maximum power demand throughout the stress relieving was 3·6 MW (about 2 kW/ton of metal treated). Supplies were led in through the duct and nozzle openings *via* stainless steel conductors welded to connexions to the heaters to safeguard against faults.

Seven days were needed to reach the stress-relieving temperature of 550°C; the rate of temperature rise being limited to 5 degC/h. After soaking for 12 h the vessel was left to cool for eleven days before it was entered. The insulation was removed after the ninth day. Tests subsequently carried out included crack-detection tests on 10% of the nozzle welds in the heat shield and 100% crack-detection tests of shell nozzle welds and gussets. Parts of the top and bottom crowns were examined ultrasonically.

All the external surface of the pressure vessel and ducts and nozzles were insulated; the photo shows the Rocksil insulation applied to the bottom crown

GEC say that with certain minor modifications to the heating system the time taken to test the second pressure vessel should be reduced.



BAND REINFORCED PRESSURE VESSELS The diagram shows the results of a test to destruction carried out on this type of vessel by John Thompson (Wolverhampton) Ltd. The hoop load is carried by reinforcing bands. If the bands are joined by circumferential welds, the longitudinal load is also carried

The Black Void Reactor Concept

The black void concept arose from considering the possibility of incorporating converter fuel assemblies in the National Bureau of Standards high flux research reactor, NBSR (see this issue p. 84). The general idea for the concept is to have a number of heavily loaded cylindrical fuel assemblies in the configuration. These will be black to thermal neutrons.

Slow neutrons returning to the fuel assemblies will provide, on fission, a fast neutron flux in the void interior of the fuel assembly. Partially moderated neutrons of intermediate energy will also irradiate the tube. The void will contain instrumented samples for fast neutron irradiations. Also, beam tubes in the moderator will provide thermal neutrons for diffraction studies.

Test for stainless steel clad elements

General Atomic's recent proposal to test stainless steel clad fuel elements is part of their programme for the development of low-power packaged reactors, *Nuclear Power* has been told. The elements will contain a uranium-zirconium hydride alloy with about 92 wt-% zirconium hydride and 8 wt-% uranium 20% enriched. The hydrogen-zirconium ratio will be about 1·7. The extension of the Triga concept to the field of unattended portable power plants, with ratings up to 2000 kWe, was announced earlier this year.

Preliminary investigations have considered both pressurized and boiling water as coolant. Thermoelectric elements for direct conversion are also a possibility, depending on the application.

• **Heavy duty capacitors** An important feature of the 10 kV, 10 μF capacitor units developed at AWRE Aldermaston in connexion with CTR work is the low inductance connexions used consisting of metal foil strips with 0-006 in insulating strips. One unit has been tested 10,000 times without breakdown. The current was 700,000 A and the ringing frequency of the discharge 1 megacycle/s. Manufacturing licences have been granted to Bonar Long & Co. Ltd, Standard Telephones & Cables Ltd, Static Condenser Co. Ltd and Wego Condenser Co. Ltd.

• **Ceramic sponges for waste disposal** Under development at Los Alamos is a new method of high-level radioactive waste disposal. Two-inch dia. ceramic spheres are soaked in liquid waste and then fired at high temperature. They are then as dense as china with practically zero leachability.

• **New probe using sound waves** US General Electric are developing a sound probe device for examination of reactor process tubes. Successful development of the device will reduce shutdown times and prevent damage to vital test equipment, say GE.

Despite the demands of a tight production schedule, the reactors at Calder Hall and Chapelcross have been used for a range of large-scale experiments relating directly to factors affecting the design, commissioning and fuel element performance of the civil stations

The contribution of Calder Hall and Chapelcross to the civil programme

by D. R. R. FAIR, O.B.E., B.Sc., A.K.C., Deputy General Manager, Chapelcross Works, and T. N. MARSHAM, B.Sc., Ph.D., Superintendent, Reactors, Windscale and Calder

THE INTENSIVE INVESTIGATION and development programme carried out in aid of commissioning and operation of the Calder reactors has produced much information of direct benefit to the design and operation of the civil stations. However, due to the many differences between the stations this programme alone would have left untested a number of important features until the commissioning of the first civil station had been completed.

A comparison of conditions in the Calder and civil reactors shown in Table 1 suggests that the Calder and Chapelcross reactors would be of limited value for testing the more advanced aspects of the civil station designs, particularly as they had been designed solely as production units without the instrumentation and flexibility normally associated with research reactors. However, careful analysis of civil reactor problems showed that minor alterations to Calder operating conditions, equipment and a small allocation of operating time and core space for experimental purposes would increase enormously the value and extent of the information coming forward in aid of the civil power programme. Examination showed that the total cost of such a research programme in the production reactors would be well justified in reducing uncertainty limits in the design, commissioning and operational programmes in the early civil reactors. Much of the information would be unobtainable from other facilities, and for certain other data, the costs compared favourably with the charges for irradiation space in research reactors.

In certain respects the different conditions in Calder have definite advantages in the investigation of civil reactor problems. For example, the changes in graphite properties with irradiation such as growth and energy storage are greater at lower temperatures and vary rapidly over the lower ranges prevailing in Calder which overlap those in the civil reactors. Examination of graphite irradiated in Calder has thus been particularly valuable in specifying satisfactory civil reactor conditions. Irradiation of graphite in high flux research reactors to provide accelerated life tests did not provide data capable of direct application to civil reactors as the phenomena are significantly dependent on dose rate and neutron spectra; Calder results have

CALDER REACTOR EXPERIENCE

The first CEGB nuclear power stations at Berkeley (1) and Bradwell (2) now coming into service were designed before actual operating experience of the Calder Hall (3) reactors was available. The major differences are in core size, fuel rating, fuel element design, fuel charging and reactor control systems. These represent considerable extrapolations from the reactor experience then available. Subsequently, the very satisfactory five years operating experience of the first Calder reactor (4) and some 20 reactor years of the similar units at Calder and Chapelcross with plant utilization factors of about 85% at power levels substantially above design has confirmed the essential soundness of the gas-cooled reactor system for large-scale electrical power generation.

been found essential in relating the results of these tests to civil reactors. The off-load refuelling arrangements normally prevent testing of certain features of the civil reactor fuel elements' design and necessitate careful planning of experimental work if excess outage time is to be avoided. However, they do permit a large amount of in-pile

TABLE I *(A comparison of Calder and civil reactor conditions)*

	CALDER	BRADWELL (2)	SIZEWELL (7)
Reactor thermal power, MW	220	538	950
Average fuel rating, MW/tonne	1·7	2·1	2·9
Maximum fuel rating, MW/tonne	3·9	3·8	4·7
Nominal maximum can surface temperature, °C	420	445	454
Fuel element length overall, in	41	39	41
Uranium bar diameter, in	1·15	1·15	1·10
Standard channel diameter, in	3·6–4·2	4·2	3·85
Channel diameter (sleeve removed), in	4·6–5·2	..	..
Type of fuel element finning	Transverse	Polyzonal	Polyzonal
Coolant pressure, lbf/in²g	115	147	279
Coolant inlet temp., °C	145	180	214
Coolant outlet temp., °C	335	390	410

instrumentation to be associated with experimental irradiations and core physics experiments and this has proved of great value. Differences in operating temperature and fuel rating can generally be surmounted but the combination of highest fuel rating and temperatures does not necessarily provide the most onerous conditions for fuel elements. The only systematic mode of fuel failure observed to date has resulted from the low ductility of the original magnox cladding at the lower temperatures in the core; irradiation in Calder has provided a very stringent test of the various methods adopted to improve ductility for the long irradiation civil fuel elements. A very important advantage resulting from the use of large production reactors for fuel element testing is the ability to test a number of variables at the same time, each involving a sufficient number of fuel elements to provide results of the necessary high statistical significance. In most cases these experiments may be performed without adversely affecting production. Interpretation of core physics data as a function of fuel irradiation is simplified for the bulk discharge schemes of the Calder reactors compared with the continuous refuelling of the civil reactors and leads to earlier assessment of high irradiation effects.

Accordingly a defined proportion of Calder and Chapelcross reactor time and production was assigned to experimental work directly in aid of problems arising in the design, commissioning and operation of the civil nuclear power stations. Charges were made so that product costs were not affected.

ORGANIZATION OF EXPERIMENTAL WORK

Problems of planning and control exist when the experimental work is carried out in reactors designed for the purpose; they are even greater when this work is carried out in reactors operated to a tight production schedule. The production reactor environment is carefully defined at all stages to ensure maximum output with safety to both personnel and plant. Manuals specify the plant in great detail and operating procedure manuals are provided for every task which has to be undertaken in an approved and standard manner. To successfully insert into this fairly rigid environment an experimental programme of the size and scope undertaken at Calder Hall and Chapelcross, it has been necessary to pay great attention to the planning and programming of the experiments. Although the procedure for authorizing and achieving experimental irradiations described here is necessarily complex, in practice it has been flexible enough to enable experiments to be loaded with a minimum of delay and with the guarantee of careful safety assessments. The effort expended in this field, before the experiment, has been well worthwhile on the basis of both economics and safety.

There are four main stages to each experiment on a reactor or to each experimental irradiation in a reactor:

1. *Preliminary proposal and feasibility assessment.* The proposer prepares a preliminary scheme which is discussed with the operational and technical management at the actual sites. Details of material requirements, time scales, reactor availability, and any calculations which will be required for the design of the experiment or assessment of its safety under both steady and transient conditions are obtained. Preliminary notification is given to the Technical Directorate at Headquarters and the site concerned nominates a responsible person as liaison officer for all matters on this particular experiment.

2. *Detailed final proposal leading to experimental authorization.* The proposer prepares a detailed document which gives complete information of what is proposed and how it may be achieved. It records all the supporting calculations; contains predictions of the performance of the experiment under stable and transient conditions; details the additional instrumentation necessary and how the data from this instrumentation will be used to ensure reactor safety. The document reports information concerning stability and endurance of the experiment and records out-of-pile laboratory and rig experimental evidence. A run-down programme for the experiment is specified as is the necessary post-irradiation examination. Details are given of handling trials carried out on the experimental equipment to ensure that it can be successfully loaded and unloaded from the reactor.

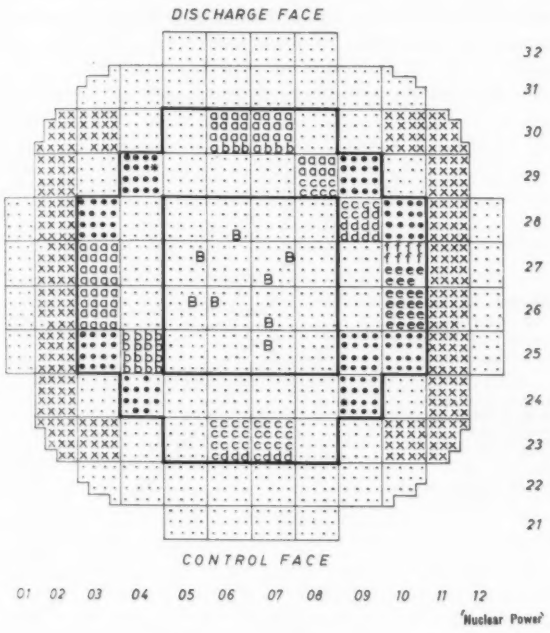
   The final proposal is circulated to the site concerned, to other sites, and to the Safety Branch by the Technical Director. After receipt of the preliminary proposal the site concerned with the experiment makes arrangements for any additional handling equipment and extra operational stores that may be necessary.

   If the safety assessment of the experiment indicates that irradiation may be achieved without infringing safety standards, and if the economic assessment is such that the costs are considered justified then the Technical Director will issue, at least 28 days before loading or setting up of the experiment is required, an 'Authority to Charge' document.

3. *The insertion and set-up of the experiment and its subsequent operational control leading to discharge*

from the reactor. Preferably one month, but certainly not less than 14 days before the date on which the experiment is to begin, the proposer must have made available to the site concerned all of the necessary materials, extra instrumentation and special fuel elements, together with the necessary experimental spares.

Before the experiment is loaded or set up in the chosen reactor, the site management must give its final approval and the necessary executive orders. The actual performance of the experiment or experimental irradiation is often the easiest part of the whole



a, b, c, d, e, f experimental chromium/uranium alloys zirconium alloy canned Calder fuel
* experimental neutron sources
X welding experiment
B Berkeley replica fuel

Irradiation experiments in Chapelcross No. 3 reactor (Fig. 1)

endeavour when compared with the detailed supporting work which precedes it and the practical expertise necessary for the successful loading and unloading. The day-to-day control is exercised by the reactor management and is covered by similar detailed operating instructions and operating limits documents to those that exist for the non-experimental part of the core. The decision to discharge all or any part of the experiment for any reason is entirely in the hands of the operators who, at all times, consider the safety of the system their first and major responsibility. Certain experiments which require prolonged periods of irradiation may have complicated run-down programmes, and the continued irradiation of the experiment may be dependent upon re-authorization after the post-irradiation examination of channels discharged at intervals as the experiment proceeds. The frequency of such reviews which may be considered necessary during the life of the experiment are laid down in the proposal document.

4. *Post-irradiation assessment*. If the experimental irradiation has involved the use of prototype fuel elements, most of the post-irradiation examination and assessment will be undertaken by the Authority's specialist laboratories. However, the reactor site concerned will normally furnish an interim report on what was observed during the discharge of the elements concerned, together with photographic evidence of any items of interest. If the experiment has involved the operation of the reactor in a non-standard manner, then the results and their implications are assessed in the first instance by the site Technical Department and a report is issued recording the information, observed data and conclusions reached.

Reference has been made earlier to the improved output, compared with design, of the Calder and Chapelcross reactors and the on-load performance has been achieved from reactor cores such as that shown in Fig. 1 which has as much as 35% of the fuel channels containing experimental irradiations.

COMMISSIONING MEASUREMENTS FOR CIVIL REACTORS

The civil stations are facing a somewhat different problem in commissioning their reactors than those faced by the AEA in commissioning Calder and Chapelcross. The AEA reactors return repeatedly to the start-up state of a reactor with a completely unirradiated core. The civil stations will use on load charge and discharge equipment to achieve an equilibrium core irradiation state. Consequently, the measurements made during the civil station commissioning are required not only to measure the parameters concerned at zero fuel irradiation but also to check the theoretical methods which will be used to supplement the rather small number of direct measurements of core conditions possible in normal operation when equilibrium fuel cycle conditions are reached. In general, the civil stations are applying well tried techniques for commissioning measurements. However, in certain cases, due to increased size or differing mode of operation of the civil reactors, new techniques have had to be developed. So far as possible the new techniques have been simulated and tested in the AEA reactors in order to discover any practical difficulties or limitations that may be involved. These tests have extended over the whole field of commissioning work.

Control rod calibration

The methods of control rod calibration have evolved during the commissioning of the AEA's eight production reactors. The calibration of the control rods in the supercritical region, over the range of rod movement for which the reactor can be made critical, is carried out by balancing excess pile reactivity against uniform air poisoning. The method is well established and the reactivity scale for reactor operation thus derived has an acceptable uncertainty of about 2%. The subcritical range of control rod movement extends from full insertion to the rod position at which the reactor can be made critical. From the operational safety standpoint the important subcritical result is the end point of the rod calibration, i.e. the amount

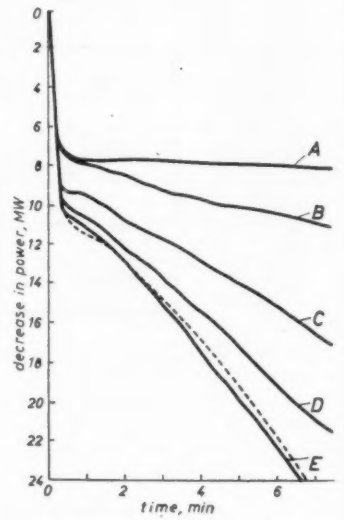
of reactivity held by the control rods at full insertion and hence the margin by which a reactor is subcritical when shut down. Variations of five main methods of subcritical calibration have been investigated at Calder and Chapelcross so that the accuracy of the determination of the full insertion capacity of the control rods could be assessed for these reactors and in order that the best method for calibration for the civil reactors could be recommended with confidence.

The subcritical counting method observes the change in neutron population either in the core or in the thermal column when the control rod positions are varied from full insertion to the position for criticality or the number of control rods fully inserted in the core is varied. Measurements have been made both with and without a neutron source in the core. The results have been treated both by normalizing the sub-critical and supercritical calibrations at the critical point and also by three different methods of extrapolation. The error margin thought to be associated with earlier measurements is $\pm 0{\cdot}2N$ on a total capacity of six niles; (a nile being the term used to express 1% reactivity) but it is considered that the final method of extrapolation has given a better discrimination: an uncertainty of $\pm 0{\cdot}1N$ is thought to be appropriate. The control rod bank method of determining the reactivity held by a group of control rods at full insertion depends upon the hypothesis that the reactivity held by the full group can be simply related to the reactivity held by suitably chosen sub-groups. Although the method is open to the objections that no theoretical correlation is available, that results are dependent upon the choice of suitable patterns for sub groups of rods and that the mutual reactivity interaction between groups of rods is not established, satisfactory results have been obtained. The method is judged to be useful for backing up the evidence given by other methods. Two transient response methods have been investigated, the rod drop and source jerk methods. In the former method the critical reactor is shut down from a steady state by causing the rods to fall together under gravity to the fully inserted position. The neutron flux decay is observed by ion chambers connected to recorders. The ratio of the magnitude of the flux at any instant of time after insertion to the flux in the critical state can be related to the reactivity inserted and hence to the full insertion capacity of the control rods. The source jerk method called for the ejection from the reactor core by pneumatic means of a neutron source of one curie (gamma) activity. By a comparison of the slopes of the integrated neutron count rates versus time, before and after ejection of the source, the value of a ratio, which may be simply related to reactivity, is obtained. The results of the transient response methods are not at present considered to be as satisfactory as the subcritical counting method but further work is being undertaken to refine the methods because they have the considerable advantage over the subcritical method that they can be carried out more readily on an operational reactor. A fifth method, investigated after the commissioning of the last of the AEA reactors, has made use of the subcritical neutron count rates determined for safety reasons during the loading of the initial fuel charge of the reactor. The validity of the procedure has been tested by comparing the estimated value of reactivity thus determined with the accepted value for the reactor concerned. The method has been shown to give a satisfactory result in spite of using relatively 'rough' data obtained from a safety monitoring programme. Determination of full insertion capacity by this method offers a substantial saving in reactor time over the alternative methods discussed, but further experimental investigation is needed before it can replace the subcritical counting procedure.

Gas flow measurements

The gas flow up each fuel channel is adjusted by gagging the channel so that the flow matches the rate of heat production of the fuel elements in the channel. The first gas flow experiments performed on Calder reactors were designed to check the installed gagging patterns. The salient feature of the results of these experiments was the wide variation in the flow rates measured for nominally identical channels. As a result of this experience more careful measurements were planned for the Chapelcross Reactor No. 2 which has graphite sleeved fuel channels. However, in spite of improvements in instrumentation and more careful calibration of anemometers before and after the experiments, a considerable scatter was again observed in the measurements obtained from nominally identical channels. This fact, taken in conjunction with the uncertainty in relating experimental measurements to the conditions of full power operation, has meant that flow rates under normal operation have been known only approximately. It follows, therefore, that fuel temperatures in uninstrumented channels also have been known only approximately. An extensive flow rate measurement experiment was, therefore, mounted in Chapelcross Reactor No. 4 designed to discriminate the following components of variation in channel mass flow:

(i) errors in flow measurement
(ii) gas and frictional resistance in nominally identical channels
(iii) changes in gag size
(iv) radially dependent effects, independent of (iii)
(v) azimuthally dependent effects



Results of control rod insertion equivalent to 15 milliniles (Fig. 2)

experimental results
A 203 MWd/t
B 399 MWd/t
C 600 MWd/t
D 791 MWd/t
E 931 MWd/t
—— calculated result for 931 MWd/t

'Nuclear Power'

(vi) special channels (i.e. absorber channels)
(vii) Reynolds number dependent effects.

This experimental work has provided a best estimate of mean channel flow rates at operating conditions in the AEA sleeved reactors and has identified the effect on flow pattern of the diagrid structure and the outlet ducts. It has established that there are no significant radial variations in flow rate other than those caused by changes in channel diameter, gag and diagrid structure and that azimuthal variations are significant only near to the outer boundary of the core and near the coolant outlet ducts. The work has also provided a number of general conclusions and observations on experimental procedure which will be of direct value to the civil stations before undertaking this type of experiment.

To supplement this work on methods of flow measurement and because of uncertainties in heat transfer data and cartridge heat output calculations, much effort has been directed to extending the number of direct fuel can temperature measurements. All typical cartridge temperatures can now be measured in all channels; these direct observations are being used to test and refine the computer programmes being developed to predict reactor flux and temperature conditions and which will be required to assist in controlling civil reactor fuel cycles and operating temperatures.

REACTOR PHYSICS, STABILITY AND CONTROL

When equilibrium conditions are achieved in the civil nuclear power stations, fuel will be discharged when the heat output from each channel has been about 3000 MWd/t; by this time some 35% of the original U-235 will have undergone fission and about 40% of the heat being produced will result from fission of Pu-239. The changed composition of the fuel at high irradiation materially changes the physics and kinetics of the reactors compared with conditions normally experienced in the Calder reactors in which bulk quantities of fuel are replaced every year. This is particularly so for conditions prevailing when basic measurements are made during commissioning at which time the fuel is unirradiated.

Uncertainties in the extrapolation of data to high irradiation conditions affect design and operational planning for the civil stations. In particular, the variation in reactivity of the core with fuel irradiation may affect the achievable fuel burn-up and also determines the amount of flux flattening which may be employed to allow as many channels as possible to operate at maximum rating conditions. The changes in reactivity resulting from changes in fuel and moderator temperatures vary with irradiation and temperature and have important implications on the design of the reactor control system, safety arrangements and operational techniques.

To establish the accuracy of the theoretical methods employed which used only basic data or large extrapolation from previous reactor experience, it was decided to supplement the normal information arising from Calder and Chapelcross by a special two-year experimental programme on Calder Reactor No. 3, during this time a complete charge would be irradiated to an average exposure of 1000MWd/t. The maximum cartridge irradiation would be about 2000MWd/t and the bulk charge would cause the reactor to behave in certain important respects in a similar fashion to a civil reactor using continuous charging at a rejection level of 2500MWd/t.

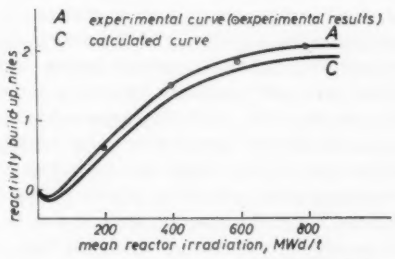
The experimental programme had the following objectives:

(1) to obtain accurate measurements of basic reactor parameters as a function of fuel irradiation
(2) to examine changes taking place in reactor stability and to measure reactor transient responses to system perturbations in a manner capable of testing the theoretical methods employed in reactor kinetic investigations
(3) to obtain practical experience of all problems arising from operating an unstable reactor with a large positive moderator temperature coefficient of reactivity.

The programme was completed in September 1960 when the reactor had reached an irradiation of 1013MWd/t in terms of the original charge and had operated at a full power load factor of 87% with the experimental work accounting for some 6% of the outage time. The experimental work, which represented the combined efforts of Operations, Technical and Research and Development staff, required the development of many new techniques, both experimental and theoretical, and in particular, an increased accuracy of measurement compared with that normally required on a production reactor.

Measurement of reactor physics parameters

Measuring most of the important parameters requires the assessment of changes in reactivity on alteration of



Reactivity build-up in Calder Reactor No. 3 under operating conditions (Fig. 3)

various reactor conditions. At low power, these may be measured by using a reactivity-flux doubling time relationship corrected for irradiation conditions; but at operating temperatures and high powers at which such information is more often required, it is necessary to depend on a control rod calibration. The Calder control rods were calibrated by comparison with air poisoning at a uniform temperature and with unirradiated fuel. The practice has been to apply corrections to this basic calibration for all known changes in conditions; wherever possible these have been determined by check experiments but in other cases, theoretical corrections have had to be applied. The effect of changing reactor temperatures at zero irradiation was determined directly as an increase of 0·06% of capacity per deg C rise. The effect of irradiation on reactor parameters was calculated to produce about 6% reduction in capacity at 1000MWd/t. It was considered necessary to confirm this; but the use of air poisoning with a highly irradiated core was not acceptable. A method was employed which made use of fission product xenon poisoning. This permitted determination of the reactivity produced by a small withdrawal of control rods by

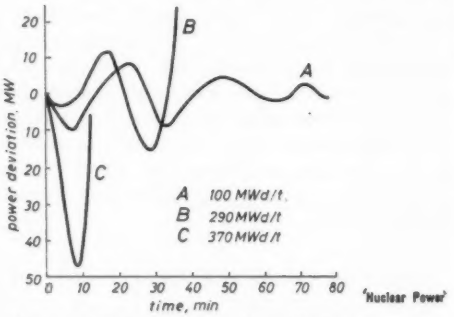
measurement of flux doubling times over a wide range of rod positions as the rods were being moved to keep the reactor just critical as the xenon decayed. This indicated that a rather larger correction was necessary. Recent theoretical work has shown the need to correct the isothermal control rod calibration curve because of the change in axial flux shape with temperature under power conditions as a result of the axial variation in temperature rise and moderator temperature coefficient. Extreme care has been necessary to include all distorting effects on the shape of the control rod calibration; uncertainties in these have contributed most of the uncertainties in many of the measurements.

Temperature coefficients of reactivity

A comprehensive series of measurements has been made to establish the variation in core reactivity with temperature changes in the moderator and in the fuel as a function of temperature and fuel irradiation. A major difficulty arises in separating the effects of fuel and moderator temperature changes, but by using a number of different techniques satisfactory accuracy has been achieved.

Uniform temperature changes have been applied at low power and temperature by injecting steam into the heat exchangers and circulating coolant gas to heat the core. At operating conditions uniform temperature changes have been applied at constant power by alteration of the heat exchanger steam circuit pressures which change the coolant inlet temperatures. Measurements of the control rod movement required to maintain constant power determined the combined fuel and moderator temperature coefficient. Assessment of the fuel coefficient separately is difficult because variation in fuel temperature quite rapidly affects the moderator and at both high and low irradiations the effect of the moderator coefficient is greater than that of the fuel coefficient. The most accurate method was to operate a reactor at low power during commissioning without forced circulation of the coolant. The resulting small natural convection allowed a large rise in fuel temperature with only a small change in moderator temperature for which a correction could easily be made. The value obtained of $-2{\cdot}7$ mN/deg C was significantly more negative than other determinations at normal operating temperatures, but this measurement was made at a temperature of only 60 deg C. Theoretical work had shown that the fuel coefficient should vary as $T^{-0{\cdot}6}$ and this was the first experimental confirmation of this effect. The accuracy of other measurements has not been sufficient to confirm this relationship precisely, but its application does considerably improve the self-consistency of various measurements and it is now accepted and applied. Another satisfactory technique has been to operate the reactor at low pressures with powers in the range 1–15 MW and about 5% coolant flow and to measure the rod movement necessary to change fuel temperatures rapidly in 50 deg C steps. Under these conditions graphite temperature changes are much reduced because of both the reduced gamma heating and the reduced coolant heat transfer, the time constant for graphite temperature responses being increased to some 200 min compared with 10 min under normal operating conditions.

Further measurements of fuel and moderator temperature coefficients have been obtained by analysis of the transient responses of the reactor to small perturbations in reactivity, inlet temperature and coolant flow. A series of such experiments was carried out with increasing fuel irradiation. Figure 2 shows the results of inserting control rods equivalent to a reactivity decrease of 15 mN as irradiation proceeded. The initial drop in power is mainly attributable to the fuel coefficient and the subsequent change depends on the sign and magnitude of the moderator coefficient. These have been analysed using both a simple point model and also using a three dimensional programme (known as STAB) on the IBM 704 computer. Fitting of these curves enables the best value of both fuel and moderator coefficient to be determined and the theoretical curve for the measurements at 931 MWd/t is shown, these corresponding to a fuel coefficient of $-1{\cdot}6$ mN/deg C and a graphite coefficient of $+7{\cdot}6$ mN/deg C.



Xenon oscillations, initially damped but becoming divergent at higher irradiations (Fig. 4)

An oscillating technique has been employed which does not depend on a knowledge of the control rod calibration. A reactivity oscillation was applied by suitable movement of two central control rods at frequencies in the range 0·2 to 1·5 cycles/min to give power changes of the order of 5%, and rod movements, temperature and power changes were recorded. A vector relationship exists between the reactivity inserted by the control rods, that associated with the power oscillation and the fuel temperature changes. If the phase angles are measured and one of the quantities is known then the other factor and hence the fuel temperature coefficient can be deduced.

These experiments have yielded a satisfactory and consistent set of measurements of fuel and moderator temperature coefficients over the range of irradiation from 0 to 1000MWd/t. Over this range the fuel coefficient at operating temperatures has a mean value of about $-1{\cdot}6$ mN/deg C and there is some evidence of a small decrease with irradiation. Correlation with theory has enabled the values that will obtain in the civil reactors to be deduced with satisfactory accuracy.

Reactivity changes with irradiation

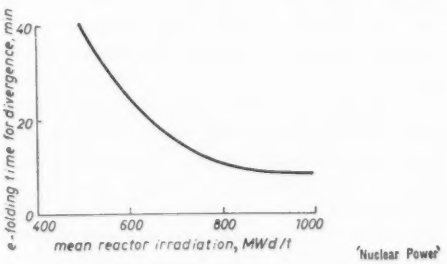
The reactivity changes occurring in the core up to the bulk irradiation of 1000MWd/t have been assessed by making a series of reactivity balances and correcting for the effects of irradiation on the capacity of absorbers loaded in the core, control rods and xenon poisoning. To supplement this data and to obtain information at higher irradiations, the reactivity changes taking place in single

cartridges have been measured by the Gleep oscillator. A consistent theoretical correlation with these measurements has been obtained and a comparison of experiment with theory is shown in Fig. 3. Use of this data to derive point and channel reactivity change curves shows that for a reactor operating with continuous channel refuelling, reactivity will not fall to the original hot poisoned value with new fuel before an irradiation of at least 4000 MWd/t.

Reactor stability

Early theoretical work indicated that gas-cooled thermal reactors, when uncontrolled, would exhibit oscillations in total power without change in distribution as a result of the interactions between the delayed effect of the xenon poisoning and the destabilizing action of the positive moderator temperature coefficient (*5*). The oscillation, initially damped and with time constants of many hours associated with the formation of xenon, would become divergent and eventually purely exponential in character. Decreasing e-folding times for the applied perturbation would occur as fuel irradiation proceeded as a result of the increasingly positive moderator temperature coefficient. The period would be limited by the discharge of fuel at the chosen limit and was expected to be about several minutes for the civil power stations under equilibrium conditions. Calculation indicated that in addition to instability in total power, the large thermal reactors could also exhibit oscillations in the spatial distribution of the power output with the total power kept constant, and therefore the reactors are to be controlled by a number of independently operated sector rods in about 10 radial zones. Theory indicated that oscillation of the flux distribution between the end of the reactors (axially) was most unlikely.

These calculations were based on simplified systems, generally point models, using only perturbation techniques. There was much uncertainty about the validity of the models for large perturbations, three dimensional effects and the basic reactor and transient heat transfer assumptions employed. No direct experimental data was available to test these calculations. In parallel with the development of more elaborate three dimensional theoretical methods for investigation of reactor stability problems, it was decided to carry out an extensive experimental programme on Calder Reactor No. 3 to improve the basic data and to test and refine the theoretical models. Although calculations showed that the Calder reactor would not experience spatial instabilities in flux, it would be unstable in total power with a decreasing e-folding time for a disturbance, expected ultimately to be about 10 min and similar to that expected in the civil stations.



Measured values of power divergence against folding time (Fig. 5)

Basic reactor data was obtained as described in the previous sections. Reactor stability was investigated directly by observing the uncontrolled response to normal core disturbances and also to applied perturbations in reactivity, temperature and coolant flow.

The changing responses as irradiation proceeded strikingly confirmed the early predictions. Figure 4 shows the initial damped oscillation and the increasingly divergent oscillations observed as fuel irradiation proceeded. The subsequent exponential decay with decreasing time constants are shown in Fig. 2 and the time constants experienced are shown in Fig. 5. As expected, the higher modes of instability did not occur, but the agreement between theory and experiment for the fundamental and most rapid mode of instability have added considerably to the confidence in the predictions of the effects of the higher modes in the civil reactors. The measured responses are being used to test and improve the more elaborate three dimensional computer programmes, notably the STAB programme which has proved extremely valuable and demonstrated a number of important effects not apparent from the former reactor point model representation.

Operational experience with the reactor in an unstable condition proved entirely satisfactory and manual control of the fundamental mode provided no difficulties. The reactor could be maintained within 2 deg C of the control temperature by adjusting the control rods on average about every 15 min. Reactor operating techniques had to be slightly modified as the moderator temperature coefficient became increasingly positive. During the experiment, the most reactive state of the reactor changed from the cold to the hot condition, and heating or cooling of the moderator had very marked effects on reactivity and magnified the effects of control rod movements. To maintain normal low rates of change of temperature, control rod movements in the direction opposing the desired change were sometimes required, but no control or safety problems arose. The reactor withstood the normal minor fault conditions which arise from time to time without incident and also a complete power failure and shut down as a result of complete loss of station electrical supplies.

Reactor kinetic calculations are needed to establish control requirements and for the safety assessment of fault conditions. As the calculations had been tested only against experiments involving small perturbations to normal operating conditions with near normal heat transfer conditions and small rates of change of temperature, it was decided to test the theoretical model by simulating a reactor fault condition with large and rapid increases of temperature under low heat transfer conditions. A Calder reactor was operated at powers increased in stages up to 90 MW and at each stage the main coolant circulators were tripped with the control rods remaining in their normal operational conditions. Fuel temperature rises of up to 130 deg C in a period of 1½ min were experienced and in all cases the measured transients agreed with previous calculations to within about 7 deg C.

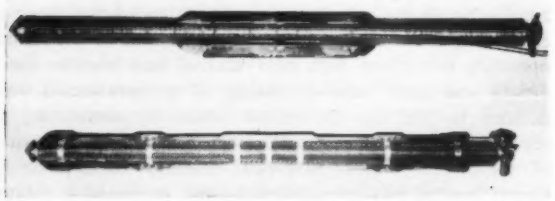
FUEL ELEMENT TESTING AND B.C.D. PROCEDURES

Whereas the uranium fuel rods for civil reactor fuel elements are effectively identical with those employed in

Calder reactors, the magnesium alloy cladding designs are markedly different. In particular, the heat transfer surfaces take various forms of spiral finning with longitudinal flow splitter blades compared with the simple circumferential fins and short support braces of the Calder fuel elements (Fig 6). The metallurgical treatment of the cans has been altered to improve the low temperature ductility and they have been designed to withstand on-load charging, thermal cycling and the larger dimensional changes that will occur at the increased irradiation levels. The design changes to meet these conditions were necessarily determined from a limited amount of irradiation experience and more extensive out-of-pile test rig work. Consequently, a comprehensive testing programme has been undertaken in the Calder and Chapelcross reactors to prove the detailed design before bulk manufacture and civil reactor loading, and also to provide advance information of any failure characteristics as a result of prolonged irradiation. In addition, a programme of irradiation trials of improved materials and manufacturing techniques is being undertaken. The Calder and Chapelcross production reactors are particularly suitable for these tests as they permit the testing of large numbers of experimental fuel elements and so yield data of the necessary statistical accuracy, as the effectiveness of a fuel element design is generally determined more by the beginning of the failure distribution curve than by the mean life. Modifications to fuel handling equipment have been relatively minor; but considerable effort has been necessary to increase in-pile instrumentation and to establish the conditions of irradiation for a charge of several fuel element types, each operating under the appropriate conditions. An essential part of the irradiation testing programme has been the detailed metallurgical examination of the irradiated fuel by the AEA Reactor Group's Windscale Laboratories.

Although the standard Calder cartridges were not intended for long irradiation they have, in practice, proved capable of sustaining irradiation periods in excess of 3½ years, and cartridge irradiations to date of 3500MWd/t.

Irradiation of a number of these channels is continuing for experimental purposes. The only problems have been an increasing tendency for the two colder elements to suffer cavitation type cladding failures due



(Top) Calder type fuel element with thermocouple attached: (bottom) Bradwell fuel element (Fig. 6)

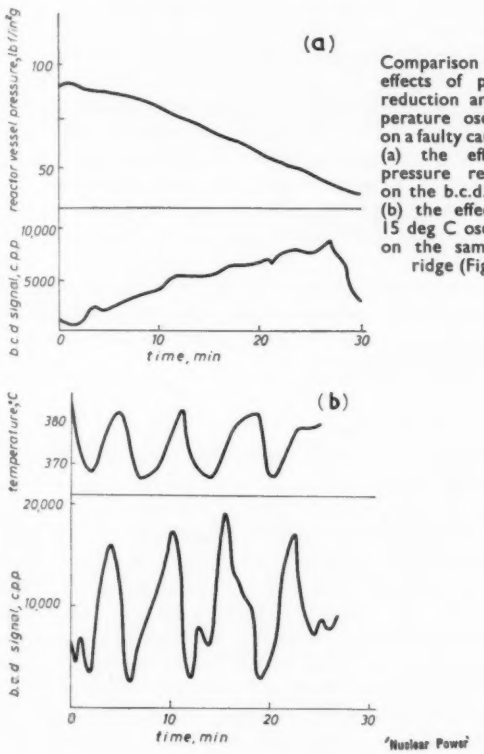
to the relatively low ductility of the magnox employed. Deformation of cartridges at the lower end of the stack has occurred as a result of the loading provided by the upper cartridges and the reduced creep strength of the uranium under irradiation — the short supporting braces being intended only for short irradiation periods. Because of the later production of the civil reactor fuel elements, the Calder fuel has so far provided all the data at high irradiations and careful measurements have been made on the changing dimensions and properties of the uranium bars. Fuel with special grid reference lines has been irradiated to provide information on any local deformation occurring. In general, deformation has been very small and no case of cladding failure of the higher temperature and higher rated fuel elements has been attributable to the effects of irradiation. Other experiments at high irradiation with Calder type cartridges are continuing to test different methods of uranium fabrication, the effects of alloying the uranium and also different cladding materials including the use of a zirconium magnesium alloy.

When considering the direct testing of civil reactor fuel, a choice of operating conditions has to be made because the designed maximum temperatures and ratings are greater than those normally present in Calder type reactors. The procedure adopted has been initially to test a single hybrid design including as many as possible of the novel features incorporated in different fuel element designs to obtain data at an early stage before designs are frozen. The next step is to test specific designs at the correct temperature and ratings which are achieved by making cartridges with slightly enriched uranium and finally to test actual fuel elements from the production line, the reduced rating with natural uranium being accepted. A deficiency in this proving programme is that because of the different pressures, all flow effects that will be present in the highest rated civil reactor channels cannot be entirely reproduced in the Calder reactors. Additional information on gas flow effects is obtained using out-of-pile test rigs.

The first in-pile test of a 'notional' civil fuel element, that is, a simplified element embodying certain of the novel features of the different civil designs, resulted in cartridge failures after a very short irradiation and subsequent examination indicated mechanical damage that appeared probably due to rattling in the channel gas flow. This instability was demonstrated in flow test rigs. They were confirmed in pile by mounting strain gauges on these fuel elements and obtaining signals of the amplitude and frequency of the strains set up by the instability. Modifications to increase the stability of the stack were subsequently incorporated and have been proved satisfactory by both in- and out-of-pile tests. Tests of actual civil fuel element designs have now been in progress for periods up to two years.

In service, the civil reactor fuel elements will experience two conditions markedly different from those in Calder reactors as a result of the on-load charging arrangements and the automatic control system. The fuel will suffer rapid thermal changes on being loaded and a result of the continuous refuelling arrangements will be that the sector control rods will make frequent significant movements to counter the reactivity effects of the insertion of the refuelling machine grab. Typically, a fuel element on loading will experience rates of change of temperature of about 100 deg C/min and channels near the sector rods will experience some 2000 thermal cycles with amplitudes over 10 deg C during their irradiation life. A considerable amount of out-of-pile simulation has been carried out to prove the suitability of the civil fuel designs. But difficulties in exactly simulating reactor conditions with the heat generation throughout the volume of the uranium resulted in experiments being carried out to examine these effects

in Calder reactors, although they are not produced in normal operation. To test the effect of on-load charging, an element was suspended in the top section of a fuel channel reflector from a control rod actuating mechanism and the reactor was brought up to full power. The fuel element was inserted into the fuel channel at a speed of 8 ft/min, the maximum temperature changes being 140 deg C/min, and irradiated for a period at the normal maximum operating temperature before being withdrawn in a similar manner. Subsequent examination showed that the element had suffered no damage as a result of the full power charge



Comparison of the effects of pressure reduction and temperature oscillation on a faulty cartridge; (a) the effect of pressure reduction on the b.c.d. signal; (b) the effect of a 15 deg C oscillation on the same cartridge (Fig. 7)

and discharge procedure. To test the ability of fuel to withstand thermal cycling a reactor has been operated for many months with two diagonally opposite control rods at the outer edge of the reactor oscillating with similar amplitudes but out of phase. This caused thermal cycling of 30 deg C amplitude in the fuel in channels close to the rods, but the overall reactor power was little effected and the majority of the fuel and the pressure circuit was not subjected to significant thermal changes. Fuel operating at a mean temperature of about 350°C has experienced 30,000 cycles and other cartridges at a mean temperature of 450°C have received 15,000 cycles without failure.

The sensitivity of the faulty cartridge detection equipment in a reactor must be related to the actual design of fuel element employed. The equipment to be used on the civil reactors is similar to that employed at Calder and has all been tested on a Calder reactor and proved satisfactory. Calder experience has been that the equipment has very adequate sensitivity for all types of failure with the exception of most infrequently occurring defects which take the form of minor weld damage and a very long leak path for fission products from the uranium fuel itself to the coolant stream. The equipment depends on the detection of the second radioactive decay of certain mainly short-lived gaseous fission products and thus the sensitivity is much reduced for fuel failures which form long leak paths. This type of fuel failure has been experienced only from damage incurred during loading or in manufacture which has escaped detection during inspection. New charges of fuel in the Calder reactors are checked for this type of defect by reducing the coolant pressure during normal monitoring by the failed cartridge detection equipment. This increases the outflow of fission product gases from defective cartridges. No difficulties have been met since this procedure was started. It was appreciated that after the loading of the first charge, this procedure would not be applicable to the civil reactors with continuous refuelling and an investigation into satisfactory alternative techniques has been carried out. This has included loading of fuel elements with known leaks of different types to determine the variation in sensitivity of the equipment and with fuel with design modifications such as the inclusion of a small uranium 'tell-tale' mounted closer to the weld than the end of the bar to reduce the length of leak paths. Experiments have also been carried out on such failures as were discovered during normal operation. Recent tests have shown that small amplitude power and temperature cycling under full power conditions can also increase the signal from these faulty elements in a similar manner to the pressure step procedure. This would be applicable to civil reactors if necessary, although it might be expected that the action of inserting the fuel with the reactor on load would itself introduce an increased signal and make special procedures unnecessary. Work is proceeding at Chapelcross and Calder to optimize these procedures. Results of a typical experiment are shown in Fig. 7 in which it can be seen that the effect of reducing pressure on the signal from a faulty cartridge was to increase the signal by a factor of 13 over steady values and the application of a 15 deg C temperature oscillation at the rate of 5 deg C/min caused an increase in signal by a factor of 10 whenever power and can surface temperatures were increasing.

IRRADIATION EFFECTS ON MATERIALS

An extensive experimental programme to investigate the effects of irradiation on non-fissile materials has been undertaken. A primary requirement has been to mount a monitoring programme to observe irradiation effects on graphite, steel and concrete in order to ensure the safety of the Calder reactors throughout their operating life. Much of this data is directly relevant to conditions in the civil reactors and this is being supplemented by an additional programme of investigation using different materials and different irradiation conditions to those required directly for Calder monitoring.

Large numbers of samples have been irradiated in all parts of the core, including fuel channels and representative regions of the pressure vessel surface. Special facilities are installed on a number of reactors which allow samples to be irradiated just outside the pressure vessel where thermal neutron fluxes of 10^9 n/cm² s. are available and handling arrangements are particularly simple. Rigs are being installed which permit the loading and removal of samples

for irradiation in the centre of the core with the reactor operating normally at full power and thermal neutron fluxes up to $1{\cdot}1 \times 10^{13}$ n/cm² s. are available. These are proving to be most useful and inexpensive facilities and are in regular use for irradiations required by the Reactor Group's Windscale Laboratories.

Graphite monitoring

Each of the eight reactors has been loaded with sufficient graphite specimens to ensure that, throughout the reactor life, specimens will be available with the same irradiation history as the moderator. Each reactor contains 90 containers of graphite specimens which have been prepared and accurately measured prior to insertion in the core. There are two main categories of container—those with specimens requiring assessment of physical characteristics, and those with specimens for chemical determinations.

Approximately every 12 months, the containers from two channels (containing both types of specimen) are discharged. In the channel containing the specimens for chemical determinations, there are 15 containers each with six pots containing two weight change specimens, one air reaction rate specimen and one carbon dioxide reaction rate specimen. Weight-change monitoring is carried out on all 360 specimens which are returned to the reactor after measurement. The air reaction and carbon dioxide reaction rate determinations are destructive and are carried out on 15 specimens only.

The 15 containers in the physics channel contain specimens for determination of growth, strength and energy release.

The growth specimen is a 1·1in cube, the size of which is lapped to a fine finish and three measurements are taken, one in line with the extrusion of the graphite and two at right angles to this line ; the measurement is made to an accuracy of some 2–3 micro-inches. The weight change specimens are heated in an oven controlled to 200°C $\pm$ 2½% for a period of 48 h immediately before weighing, in order that the weighing will be made under standard conditions ; an accuracy of $\pm$ 0·00001 gramme is achieved. Some strength cube specimens are compressed to breaking point in line with the extrusion of the graphite whereas others are compressed at right angles to the direction of extrusion. The residue of the strength cube specimens are tested in a calorimeter to obtain a measurement of the total stored energy. The energy release specimens are tested in a linear rise calorimeter to obtain a measurement of the rate of energy release with temperature.

The observed effects in the production reactors are correlated with results from the samples in high flux reactors. Correction factors have been determined to enable the results from the high flux reactors to be applied to predict the future behaviour of the graphite in the civil reactors.

Steel monitoring

The steel monitoring programme provides for the direct monitoring of the behaviour under operational conditions of the steel of the AEA's pressure vessels. The information is obtained from the examination of steel samples located in positions within the AEA reactor vessels where the neutron flux is representative of the flux to which the vessel is itself subjected and from samples located in high flux positions where the specimens are subjected to an accelerated dose rate. In both cases, the experimental programme will give advanced information for the civil power stations. In all, some 1000 canisters are loaded into the eight reactors and the withdrawal programme is planned to allow a withdrawal from one of the reactors each year for the next 20 years. The canisters which are located in the areas of accelerated neutron dose rate, are programmed for withdrawal during the years 1961-64 when the irradiation received by the specimens concerned will be equivalent to approximately 10, 20, 30 and 40 years of irradiation of the pressure vessel. The post irradiation testing of the specimens is carried out in the Authority's Culcheth Laboratories where measurements are made of tensile strength, of the transition curve from fully brittle to fully ductile fracture, of graphitization or other structural changes and of the hardness of each type of metal.

In addition to this monitoring programme, an experimental strain gauge programme has been mounted on one of the eight pressure vessels. The main equipment is a commercially available capacitance type gauge but two novel types of mechanical limit gauges have also been installed.

The programme has the dual purpose of observing the behaviour of the pressure vessel itself and of establishing the behaviour characteristics under reactor operating conditions of the gauges.

Concrete monitoring

When the Calder and Chapelcross reactors were constructed the information available on the behaviour of large masses of concrete when subjected to heat and radiation was very limited. Long term studies on the biological shield concrete of several of the Calder type reactors were, therefore, initiated to be used to supplement and interpret laboratory scale studies concurrently being undertaken at the Building Research Station at Watford. Quite extensive instrumentation has been installed in the biological shields of the fourth reactors built at Calder and Chapelcross.

There are concrete strain gauges of the acoustic type for the determination of concrete movement and temperature stresses ; moisture gauges of an electrical type for the determination of drying rate ; thermocouples in order to observe the temperature gradients within the biological shield ; reference plugs for crack observation are inserted at standard distances at cross joints ; and joint movement indicators are embedded in typical joints and operate by breaking an electrical circuit at predetermined openings. The interpretation of the measurements is being undertaken by the Building Research Station.

Acknowledgments

This paper describes a co-operative programme of experiments carried out by many members of the staff of the AEA's Production and Reactor Groups, whose efforts it is a pleasure to acknowledge. The authors are also grateful to the Nuclear Power Group for permission to publish the photograph of the Bradwell fuel element in Fig. 6.

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The principal lessons learned have been the need to treat the power generating system from reactor to alternator as a whole, and the importance of the part played by the operator in averting danger

Safety aspects of Calder Hall reactor operation

by E. L. DESBRUSLAIS, B.Sc.(Eng.), M.I.E.E., A.M.I.Mech.E., M.I.PlantE., Works Manager, Calder Hall.

THE FIRST CALDER HALL REACTOR has been in service for five years, and Calder Hall alone has over fifteen reactor years' operating experience. Throughout this period the designed safety arrangements, such as the elaborate control instrumentation and safety trips, have fulfilled their purpose of detection and prevention. But, as the reactors are prototypes, many and various types of safety investigation, sometimes tested by simulated fault conditions, have been undertaken. Some operating and control modifications have been made as a result to further improve the standards of safety and at the same time permit the 25% increase in output which has been achieved (Fig. 1).

CALDER INCIDENTS

Since reactor No. 1 started only four main incidents have occurred; all originated on conventional electrical plant and none in the reactors:

April 1958	transformer trip
June 1958	turbine valve failure
May 1959	turbo-alternator pilot exciter fault
August 1960 and September 1961	lightning effect on Grid

Modifications to plant protection arrangements have since been incorporated. Overall operation has shown that the nuclear safety measures taken have proven effective and that the highest safety standards in Calder Hall and the Calder-type reactors are compatible with maintaining high output.

The principal lines of investigation and progress have been: (*a*) All the initial limiting design conditions have been examined in the light of experience. In some cases it has been possible to reduce restrictions, in others it has been found necessary to increase them. (*b*) Measurements have been made of the effect of irradiation on reactor behaviour, to supplement theoretical extrapolations from research reactors. (*c*) Fault conditions arising in operation have been carefully studied, and the principal lesson has been the need to treat the power generating system from reactor to alternator as a whole, and to consider the possibility of linked or consequential effects following the failure of a turbine, such as damage to the pressure circuit or the reactor controls by flying parts or by flooding. (*d*) Instrumentation and automatic safety circuits have been studied in operation. The need to provide two independent trips to cover each fault condition, and the desirability of simple direct initiation of protective systems by the fault itself, have been confirmed. In addition the importance of the reactor operator in ensuring safety has been shown.

REACTOR COMMISSIONING

The time spent during commissioning on investigation of coolant circuit conditions has proved justified. Experience of operation of the first reactor subsequent to commissioning indicated that these investigations should be supplemented by measurements of simulated fault conditions.

Reactor physics measurements were made during commissioning, with particular reference to control rod capacity and reactor behaviour under fault conditions. Accurate measurement of these parameters at the time of commissioning is important if any subsequent changes in reactor characteristics are to be detected at the earliest possible stage, and transient experiments capable of repetition should be included in the commissioning programme.

Experience at Calder Hall would indicate that new factors affecting reactor operation continue to emerge for a considerable time following the commissioning of a reactor, and it is important that an adequate allowance for work of an investigational nature should be made both in the commissioning period and for a few years thereafter.

OPERATIONAL EXPERIENCE

All plant operations are governed by detailed written instructions subject to regular review and are carried out by

for irradiation in the centre of the core with the reactor operating normally at full power and thermal neutron fluxes up to $1{\cdot}1 \times 10^{13}$ n/cm² s. are available. These are proving to be most useful and inexpensive facilities and are in regular use for irradiations required by the Reactor Group's Windscale Laboratories.

Graphite monitoring

Each of the eight reactors has been loaded with sufficient graphite specimens to ensure that, throughout the reactor life, specimens will be available with the same irradiation history as the moderator. Each reactor contains 90 containers of graphite specimens which have been prepared and accurately measured prior to insertion in the core. There are two main categories of container—those with specimens requiring assessment of physical characteristics, and those with specimens for chemical determinations.

Approximately every 12 months, the containers from two channels (containing both types of specimen) are discharged. In the channel containing the specimens for chemical determinations, there are 15 containers each with six pots containing two weight change specimens, one air reaction rate specimen and one carbon dioxide reaction rate specimen. Weight-change monitoring is carried out on all 360 specimens which are returned to the reactor after measurement. The air reaction and carbon dioxide reaction rate determinations are destructive and are carried out on 15 specimens only.

The 15 containers in the physics channel contain specimens for determination of growth, strength and energy release.

The growth specimen is a 1·1in cube, the size of which is lapped to a fine finish and three measurements are taken, one in line with the extrusion of the graphite and two at right angles to this line ; the measurement is made to an accuracy of some 2–3 micro-inches. The weight change specimens are heated in an oven controlled to 200°C $\pm$ 2½% for a period of 48 h immediately before weighing, in order that the weighing will be made under standard conditions ; an accuracy of $\pm$ 0·00001 gramme is achieved. Some strength cube specimens are compressed to breaking point in line with the extrusion of the graphite whereas others are compressed at right angles to the direction of extrusion. The residue of the strength cube specimens are tested in a calorimeter to obtain a measurement of the total stored energy. The energy release specimens are tested in a linear rise calorimeter to obtain a measurement of the rate of energy release with temperature.

The observed effects in the production reactors are correlated with results from the samples in high flux reactors. Correction factors have been determined to enable the results from the high flux reactors to be applied to predict the future behaviour of the graphite in the civil reactors.

Steel monitoring

The steel monitoring programme provides for the direct monitoring of the behaviour under operational conditions of the steel of the AEA's pressure vessels. The information is obtained from the examination of steel samples located in positions within the AEA reactor vessels where the neutron flux is representative of the flux to which the vessel is itself subjected and from samples located in high flux positions where the specimens are subjected to an accelerated dose rate. In both cases, the experimental programme will give advanced information for the civil power stations. In all, some 1000 canisters are loaded into the eight reactors and the withdrawal programme is planned to allow a withdrawal from one of the reactors each year for the next 20 years. The canisters which are located in the areas of accelerated neutron dose rate, are programmed for withdrawal during the years 1961-64 when the irradiation received by the specimens concerned will be equivalent to approximately 10, 20, 30 and 40 years of irradiation of the pressure vessel. The post irradiation testing of the specimens is carried out in the Authority's Culcheth Laboratories where measurements are made of tensile strength, of the transition curve from fully brittle to fully ductile fracture, of graphitization or other structural changes and of the hardness of each type of metal.

In addition to this monitoring programme, an experimental strain gauge programme has been mounted on one of the eight pressure vessels. The main equipment is a commercially available capacitance type gauge but two novel types of mechanical limit gauges have also been installed.

The programme has the dual purpose of observing the behaviour of the pressure vessel itself and of establishing the behaviour characteristics under reactor operating conditions of the gauges.

Concrete monitoring

When the Calder and Chapelcross reactors were constructed the information available on the behaviour of large masses of concrete when subjected to heat and radiation was very limited. Long term studies on the biological shield concrete of several of the Calder type reactors were, therefore, initiated to be used to supplement and interpret laboratory scale studies concurrently being undertaken at the Building Research Station at Watford. Quite extensive instrumentation has been installed in the biological shields of the fourth reactors built at Calder and Chapelcross.

There are concrete strain gauges of the acoustic type for the determination of concrete movement and temperature stresses ; moisture gauges of an electrical type for the determination of drying rate ; thermocouples in order to observe the temperature gradients within the biological shield ; reference plugs for crack observation are inserted at standard distances at cross joints ; and joint movement indicators are embedded in typical joints and operate by breaking an electrical circuit at predetermined openings. The interpretation of the measurements is being undertaken by the Building Research Station.

Acknowledgments

This paper describes a co-operative programme of experiments carried out by many members of the staff of the AEA's Production and Reactor Groups, whose efforts it is a pleasure to acknowledge. The authors are also grateful to the Nuclear Power Group for permission to publish the photograph of the Bradwell fuel element in Fig. 6.

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The principal lessons learned have been the need to treat the power generating system from reactor to alternator as a whole, and the importance of the part played by the operator in averting danger

Safety aspects of Calder Hall reactor operation

by E. L. DESBRUSLAIS, B.Sc.(Eng.), M.I.E.E., A.M.I.Mech.E., M.I.PlantE., Works Manager, Calder Hall.

THE FIRST CALDER HALL REACTOR has been in service for five years, and Calder Hall alone has over fifteen reactor years' operating experience. Throughout this period the designed safety arrangements, such as the elaborate control instrumentation and safety trips, have fulfilled their purpose of detection and prevention. But, as the reactors are prototypes, many and various types of safety investigation, sometimes tested by simulated fault conditions, have been undertaken. Some operating and control modifications have been made as a result to further improve the standards of safety and at the same time permit the 25% increase in output which has been achieved (Fig. 1).

CALDER INCIDENTS

Since reactor No. 1 started only four main incidents have occurred; all originated on conventional electrical plant and none in the reactors:

April 1958	transformer trip
June 1958	turbine valve failure
May 1959	turbo-alternator pilot exciter fault
August 1960 and September 1961	lightning effect on Grid

Modifications to plant protection arrangements have since been incorporated. Overall operation has shown that the nuclear safety measures taken have proven effective and that the highest safety standards in Calder Hall and the Calder-type reactors are compatible with maintaining high output.

The principal lines of investigation and progress have been: (*a*) All the initial limiting design conditions have been examined in the light of experience. In some cases it has been possible to reduce restrictions, in others it has been found necessary to increase them. (*b*) Measurements have been made of the effect of irradiation on reactor behaviour, to supplement theoretical extrapolations from research reactors. (*c*) Fault conditions arising in operation have been carefully studied, and the principal lesson has been the need to treat the power generating system from reactor to alternator as a whole, and to consider the possibility of linked or consequential effects following the failure of a turbine, such as damage to the pressure circuit or the reactor controls by flying parts or by flooding. (*d*) Instrumentation and automatic safety circuits have been studied in operation. The need to provide two independent trips to cover each fault condition, and the desirability of simple direct initiation of protective systems by the fault itself, have been confirmed. In addition the importance of the reactor operator in ensuring safety has been shown.

REACTOR COMMISSIONING

The time spent during commissioning on investigation of coolant circuit conditions has proved justified. Experience of operation of the first reactor subsequent to commissioning indicated that these investigations should be supplemented by measurements of simulated fault conditions.

Reactor physics measurements were made during commissioning, with particular reference to control rod capacity and reactor behaviour under fault conditions. Accurate measurement of these parameters at the time of commissioning is important if any subsequent changes in reactor characteristics are to be detected at the earliest possible stage, and transient experiments capable of repetition should be included in the commissioning programme.

Experience at Calder Hall would indicate that new factors affecting reactor operation continue to emerge for a considerable time following the commissioning of a reactor, and it is important that an adequate allowance for work of an investigational nature should be made both in the commissioning period and for a few years thereafter.

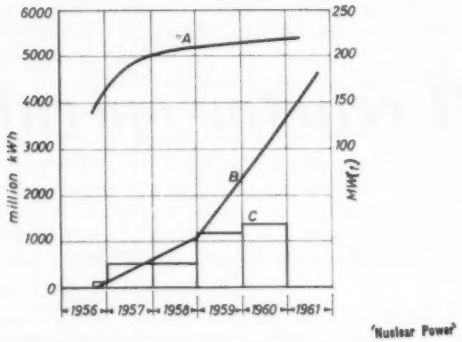
OPERATIONAL EXPERIENCE

All plant operations are governed by detailed written instructions subject to regular review and are carried out by

specified members of the operating team, appropriately trained. As a result, human errors are few, and under fault conditions the necessary action has always been carried out promptly.

Although all operators are instructed to shut the reactor down if they consider that this is necessary in the interests of safety, no case of a premature or unnecessary shut down has occurred. Occasionally delays have occurred in dealing with minor faults when instrument readings are ambiguous or misleading. In the event of a major fault the immediate action to ensure safety is taken by the reactor supervisor, and staff with suitable experience and training are always available on a shift basis to deal with consequential problems that call for special appreciation and judgment.

A proper understanding of all types of operating conditions



Calder Hall performance over 5 years (Fig. 1)

A reactor thermal power, MW
B cumulative gross electrical generation, millions kWh
C annual gross electrical generation, millions kWh

is essential and, to this end, all cases of automatic shut down, failure of protection circuits, or large temperature deviations, are carefully analysed before operations are resumed. Practical tests, including the simulation of faults, are carried out as part of this analysis. Smaller incidents are also investigated thoroughly. The importance of an adequate range of continuous or routine measurements of operating characteristics to assist this diagnostic work has been clearly shown.

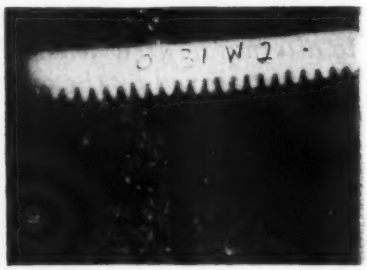
During refuelling and maintenance periods a careful control is kept on the amount of plant available for emergency service. At least two of the main coolant circuits are kept ready for use, and monitoring of temperatures and for faulty cartridges is continued. An auxiliary safety circuit replaces the main safety circuit when the latter is under maintenance. The whole of the protection equipment is tested before being returned to service.

Automatic protection circuits

Nine operating conditions are monitored for automatic protection, and unsafe levels on any of these will cause immediate shut down:

(1) high neutron flux at power
(2) high neutron flux during start-up
(3) excessive rate of change of neutron flux at low power
(4) high neutron flux in the sub-critical condition
(5) high fuel element temperature
(6) loss of coolant pressure
(7) excessive coolant pressure
(8) coolant flow unbalanced between circuits (for circulator protection)
(9) loss of power supplies to coolant circulator motors.

Supplementary trips are provided in the conventional electrical circuits connected with the main circulators, some of which are not of a ' fail to safe ' nature. Operating experience of the safety circuits has been satisfactory, and routine comprehensive checks during maintenance shut downs has confirmed their reliability. Development work in service has



This television screen picture shows a Wigner gap in the graphite core of reactor no. 1 and the graduated scale attached to the camera. During 5 years of operation the original gap of 0-120 in closed by 0-014 in (Fig. 2)

been devoted largely to the improvement of reliability of power supplies to the circuit and to the reduction of spurious signals.

Control rods

During preliminary testing prior to loading the first reactor, it was found that moisture driven off from the graphite caused corrosion of the bearings in the gear trains of the control rod mechanisms. This has been eliminated by pre-drying the graphite and taking precautions against ingress of moisture during fuel changes. No control rod has failed to enter the core correctly where a trip under operating conditions has taken place. Over one hundred such trips have occurred.

IRRADIATION EFFECTS

Failed cartridge detection gear

Local high temperatures in fuel elements, resulting eventually in the rapid failure of the magnesium alloy can, may be caused by the build-up of a mound of uranium oxide following a minute perforation of the can in a position (e.g. the end cap weld) involving a long leak path from the surface of the uranium fuel. Detection of fuel can failure depends upon highly sensitive counting of fission product activity in samples of coolant gas drawn from each fuel channel in turn. Normal failures give an indication of leakage before the perforation has developed far enough to make discharge of the element difficult or complicated. Failures involving long leak paths do not always give such preliminary warning. To aid the early identification of this type of failure, arrangements have been made to initiate reactor shut down on receipt of a signal of the rapidly increasing leak rate characteristic of this mode of failure.

Graphite

At each major reactor shut down, chemical reactivity and Wigner energy storage in the graphite core are monitored by measurement of special samples or of small pieces of the main moderator removed for the purpose. Television screen pictures are also taken of the graphite core and Wigner gaps in the reactor to check for growth (Fig. 2).

Pressure circuit

A complete visual inspection and survey programme is being followed on the heat exchangers and duct work (Fig. 3), although inspection of the reactor pressure vessel itself is not possible. No deterioration, signs of corrosion or accumulation of radioactivity likely to limit the life of the plant or future inspection has been observed in five years' operation of Calder Reactor No. 1.

Early on, results of the examination of the effects of irradiation on test specimens of steel led to arrangements being made to prevent the temperature of the pressure vessel falling below 110°C. Strain gauges have been fitted to the pressure vessel of one of the Chapelcross reactors, and a continuous check is kept on the dimensional stability of the pressure vessels; no distortion is apparent.

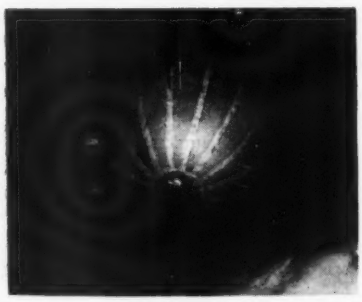
IMPORTANT FAULT CONDITIONS

There have been four important incidents at the Calder Hall Station. All originated in the turbine or electrical plant, not in the nuclear reactors, though each affected the reactors. No injury to personnel or release of radioactivity occurred, and in one case only was there damage to plant. Analysis of the earlier occurrences indicated the need for modifications to the plant protection arrangements, and these have now been incorporated.

Feed water failure

Whilst checking the protection on a spare transformer the 'on line' 11/3·3 kV transformer tripped. At the time, this latter transformer was supplying reactor heat exchanger feed water pumps, condenser cooling water pumps and turbo-alternator auxiliaries which all shut down. The cause of the trip was later determined to be faulty wiring in the protection circuits. The loss of feed water supply to the heat exchangers and consequent reduction in heat removal from the circulating coolant gas caused the temperature of the gas returning from the heat exchangers to rise to 173°C in five minutes from the normal operating limit of 150°C, and temperatures of the lower graphite to rise by 10%. These high temperatures operated alarms.

Remedial action in the turbine house was taken rapidly. On loss of the main feed pump, the emergency d.c. pumps were started manually and the turbines tripped manually within two minutes because of loss of condenser cooling water. The transformer was brought back into service and normal feed water supplies were restored about five minutes later.



For plant inspection, an inflatable balloon is used to seal off one of the bottom 54 in main gas ducts (Fig. 3)

As a result of investigations which followed this incident, interconnexions were provided for the feed water suction and discharge ranges for the two reactors feeding each turbine house. Arrangements to provide low pressure feed water from other sources for the removal of reactor residual heating after shut down, using fire pumps in an emergency, have been made.

Turbo-alternator accident

The accident to No. 5 turbo-alternator on June 28, 1958, took place during the commissioning of the turbo-alternator associated with Calder Reactor No. 3. Previously it had been run only for short periods for testing and checking of protection circuits. The machine was running on full available load when the reactor supplying steam to the turbines had to be tripped. At that time an intertrip facility was in use, so that when the reactor was tripped the alternator was also tripped and automatically disconnected from the electrical load. On this occasion, although the low pressure steam supplies were shut off, the high pressure steam valves did not close and consequently when the electrical load was disconnected the turbine overspeeded and disintegrated.

Investigation showed that the accident had been caused by the coincident failure of the turbine H.P. governor valve and the H.P. runaway stop valve to close after the alternator circuit breaker opened. This failure of the valves to close was caused by fine steel shot which had been carried by the steam from the heat exchangers into the turbine pipework. The shot finally lodged in the guides and the glands of the H.P. governor and H.P. runaway valves causing the spindles of both valves to jam in the glands or guides.

Steel shot had been used during construction of the heat exchangers, and later investigations revealed a quantity of similar shot lodged in heat exchanger circuits even though rigorous control and testing methods had been applied to eliminate it during erection.

As a result of this incident additional steam circuit cleaning methods were introduced. The turbine governor and runaway stop valves have been modified to increase their tolerance to hard particles by fitting hardened steel nitralloy spindles and guides, and the design of the valve modified to provide larger clearances between the spindles and the guides. The frequency of governor testing and surveys has also been increased. Automatic tripping of the alternator main circuit breaker on tripping the reactor has been eliminated, because there is ample time to unload the associated alternators. This modification has proved completely satisfactory.

As damage to pipework in the turbine houses or to the cooling ponds from flying parts could result in flooding, affecting essential electrical equipment, or immersion of the air cooling system intakes for the main gas circulators, suitable protection has been provided. Similar protection against flying parts has been provided for the reactor control rooms and the carbon dioxide storage plant. For similar reasons duplicate carbon dioxide supply mains have also been provided to each reactor.

Electrical system disturbance

Due to a fault on the pilot exciter on No. 1 turbo-alternator, a section of the site mains electrical supply suffered several voltage fluctuations of about 20% for a few seconds. Although Calder 'A' and Calder 'B' were running interconnected via the 132 kV Grid, the voltage disturbance was almost completely confined to Calder 'A' due to the supply arrangements.

On Reactor 2, due to differing time constants of the field trip relay, the voltage disturbance caused the 11 kV oil circuit breaker to the induction motors to trip and consequently initiated an automatic reactor shut down and automatically started up the auxiliary pony motors on the blowers. The reactor operator however pressed the reactor emergency stop button within ten seconds of the disturbance. The recorder charts show that this action coincided with the operation of the automatic shut down trip.

On Reactor 1, as a result of the voltage surges, the induction motors driving the Ward Leonard motor generator sets dropped speed and consequently the voltage of the constant voltage exciter also fell. This exciter supplies the fields of the blower motor and Ward Leonard generator through circuit breakers which tripped as a result of the fall in voltage, before

the circuit breaker to the induction motor could trip. When the system voltage returned to normal, the induction motors for the Ward Leonard generators pulled back to speed as they had lost blower load. In consequence the Ward Leonard motor generator sets continued to run, but as the circuit breakers in the fields of the Ward Leonard generators and blower motors had opened, the main drive motors stopped driving the circulators. Further, as the auxiliary motors and reactor safety circuits are only brought in automatically when the 11 kV oil circuit breaker to the induction motor opens, the pony motors did not start up and automatically take over when the main drive motors for the blowers slowed down, nor did the control rods trip in automatically to shut down the reactor, because such action is initiated through the induction motor master trip relay. The reactor operator pressed the emergency stop button ten to fifteen seconds after the loss of the main circulators. The control rods would have been inserted automatically had the temperature of the fuel elements risen by 20°C, but the pony motors would not have started automatically. The temperature rise on the reactor was less than 20°C and was over within a minute. Had the operator failed to take appropriate action, the temperature rise of the fuel elements would have operated a separate trip to shut down the reactor.

Investigations disclosed the detailed sequence of events, and modifications have been made to the automatic protection gear to prevent this type of fault. Arrangements have also been made to facilitate manual starting of the pony motors and to safeguard power supplies to the instrumentation under fault conditions.

External grid disturbance

The Calder Hall plant was connected to the National Grid on August 27, 1961 by two lines northwards and one southwards. On this occasion a section of the southern line was disconnected from the national supply and Calder was supplying Barrow to the south. A severe fault, probably caused by lightning, developed on the northbound lines, which caused a Grid voltage drop of about 24% at Calder to operate the overland transmission line protection, thus isolating West Cumberland and Barrow from all Grid supplies. All four Calder reactors and eight turbines were operating at the time. As a result of the voltage depression (which was recorded on the disturbance recorder at Calder), all induction motors driving the Ward Leonard generator sets for the gas circulators fell in speed, and due to the torque characteristics of the machines, were unable to return to speed when the supply voltage returned to normal. The gas circulator speeds thus continued to fall, and consequently the voltage of the constant voltage exciter supplying the fields of the Ward Leonard generator and motor also fell. The field breakers of the d.c. machines operated on low volts and tripped the main a.c. breakers which in turn tripped the reactors.

The alternators continued to run on residual heat from the heat exchangers and tried to supply the 35 MW of connected external load, but with all the reactors shut down, steam pressure fell. The alternators had to be tripped, leaving the site without any a.c. supplies as all the Grid lines remained disconnected. Upon the reactors being tripped the emergency gas circulator pony motors came on automatically, as they are supplied from the battery for the d.c. guaranteed supply system. Later, when all main a.c. supplies were lost owing to the alternators being tripped manually, the emergency diesel driven d.c. generators started automatically, and kept all emergency services for reactor cooling in operation until the Grid supplies were restored some twenty minutes later.

The reactors experienced only a normal automatic shut down and all emergency arrangements functioned satisfactorily. Of the sixteen circulator drive pony motors on the site, one failed to start automatically owing to a minor electrical fault, but adequate cooling was available from the other machines.

After full testing of the protection circuits and other plant which all proved to be satisfactory, the plant was started up again, and generation recommenced some fourteen hours after the fault. Again considerable detailed analysis of the sequence of events was undertaken. To confirm conclusions previously reached, the effect of voltage depression on the 11 kV induction motors was afterwards simulated by reducing the voltage of one of the Calder alternators which had been arranged to supply the circulator drive induction motor of a shut down reactor.

The incident revealed no deficiencies in the safety circuits or emergency arrangements. Modifications put in hand after the electrical disturbance of May 18, 1959, particularly the alteration to the circulator tripping arrangements and instrument supplies, were shown to be justified, and the train of events was due to the particular characteristics under prolonged voltage depression of the blower drive installed at Calder.

A somewhat similar incident occurred during the evening of September 2, 1961 when, as a result of a lightning strike on the Grid lines supplying Windscale and Calder Works, the voltage on the blowers of all four reactors dropped by about 20%. Because of the size and duration of this voltage depression, three reactors tripped out of operation automatically. The fourth reactor continued operating as the main blowers on this reactor were being operated below maximum load and therefore continued to supply power to the Barrow and Egremont areas of Cumberland and Windscale Works. The three reactors were restarted immediately and connected back on to the Grid during the early hours of the following morning. All the nuclear, electrical and mechanical protective devices operated correctly.

The principal lessons of these incidents are:

(*a*) the need to study from the safety point of view not only the reactor system itself, but its interconnections with the steam raising circuits, the turbines, transformers and switchgear, and with the incoming Grid supplies
(*b*) the importance of thorough investigation not only of accidents, but of potentially dangerous occurrences which do not actually lead to an accident
(*c*) the importance of the part played by the operator in averting danger.

HEALTH PHYSICS

The plant was designed to provide shielding to reduce radiation to acceptable levels in all working areas accessible during operation, and to provide complete containment of contamination during the handling of irradiated fuel. These arrangements have been generally effective, but additional precautions have been developed along the following lines:

(*a*) to guard against accidental exposure to irradiated fuel during discharging operations, fixed radiation alarms have been installed
(*b*) special precautions including the wearing of protective clothing are used to protect personnel engaged in refuelling, in case any contaminant is released. Similar precautions are adopted when maintaining parts of the pressure circuit.

The radiation dose received by reactor personnel has averaged 1·5 rads per annum during the past five years compared with the permissible maximum of 5 rads per annum.

To choose a fuel cycle for civil magnox reactors cautious operator judgements will be necessary as sufficient accurate data is not yet available

Selecting a fuel cycle for magnox reactors—1

by N. L. FRANKLIN, B.Sc., M.Sc., Ph.D., Technical Director, A. JOHNSON, B.Sc., and E. CLOUGH, B.Sc., Production Group, UKAEA, Risley

THE TYPES OF FUEL CYCLE available to a magnox reactor were outlined in a definitive paper in 1958([1]), and were reviewed from the designers' viewpoint in 1959([2]). These papers indicated the main considerations in the selection of a cycle. In particular, the change of point reactivity with irradiation was related for various schemes to the overall reactivity and output from the reactor; the role and statistical aspects of fuel element failure were investigated and the effect of the fuel cycle and the fuel failure pattern upon the requirements for fuel handling capacity were investigated. No new basic concepts have emerged since these reviews. Nevertheless experience has been gained of fuel performance in a physical and reactivity sense during the last two years, largely from the Calder and Chapelcross reactors. There is some knowledge of the type of failures which develop in practice and their rate of development. Furthermore, the importance of conditions in individual channels to the operating criteria and output of the reactors has become more obvious and means have been sought to predict these conditions from a feasible number of measurements. Finally, the date at which the fuel cycle must be selected for the first civil magnox stations is now very close and careful analyses, depending upon data which cannot yet be available to sufficient accuracy, may be replaced by cautious operator-judgments. The reactor management see the fuel cycle as one of a series of inter-related decisions on operational policy which they are called upon to make. In these rather practical conditions, the analysis ceases to be general; the extent of the experience on individual types of fuel element, the reactivity available for a particular reactor and fuel charge, and specific design features in instrumentation or fuel handling, all become important.

FUEL CYCLE DECISIONS

The real problem of fuel cycle selection is one of lack of information on available reactivity, fuel endurance and modes of fuel failure. The first part of this two-part article deals with the data which affect decisions on fuel cycles under the headings

- Fuel operating criterion
- Coolant and flux distribution
- Fuel element performance
- Charge/discharge machine capacity

and with the analysis of fuel cycles divided into three parts

- Fuel logistics
- Reactivity and power
- Detailed flux and temperature studies

The second part of the article will describe types of fuel cycle available to magnox reactors in the light of these considerations.

RELEVANT DATA AND CRITERIA

The choice of fuel cycle affects both the fuel and capital component of the unit cost at a station, the former via the fuel utilization and the latter by its influence on station output and availability.

Fuel operating criterion

In an operating reactor there will be a pattern of temperature and coolant effects in each channel which may be described without excessive loss of information in terms of a few numbers of which T_{sm} the maximum can temperature, T_u the maximum uranium temperature and perhaps C_{max} the maximum creep effect of some limiting component under gas forces or stacking loads, might be examples. If irradiation and endurance trials on the fuel have been adequate and purposeful, the relevance of particular numbers to the fuel endurance will have been established. The magnitude of the maximum credible transient will also have been established by calculation supported by trials; together with knowledge of the incidence temperature for a magnox-CO_2 reaction,

1. Gallie, R. R., Gott, H. H., and Colmer, F. C. W., 'Problems of Fuelling in Industrial Calder Hall Type Reactors,' Geneva A/Conf. 15/P. 37.
2. Grant, P. J., 'Fuel Cycle Optimization in Power Station Design,' *Nuclear Power*, 1959, July.

this will lead to a maximum number for, e.g. T_{sm}, under operating conditions immediately before the transient.

When all the channels of the reactor are considered there will be a statistical distribution of the relevant properties T_{sm}, T_u, C_{max} etc. Any such distribution can be considered to be constituted of two parts—a systematic component and a random element—and experience from rig measurements and from a programme of work in the Calder and Chapelcross reactors, indicates that random and systematic components are of the same order of magnitude with the latter, in general, the larger. The change of fuel properties under irradiation, the consequent changes in the relationship between flux and coolant flow patterns, the distribution of absorbers, empty channels, or enriched fuel, are all important contributors to this systematic component of variation. In general terms, therefore, the choice and implementation of a particular fuel cycle operation affects the channel to channel distribution of T_{sm} and other important properties.

If generation capacity is not limiting, the output of a reactor is likely to be determined by a maximum permissible value of one or more of the properties T_{sm}, T_u, C_{max} etc. Such values may be fixed by fuel endurance. In this case, unless a rather disastrous failure were possible, a value such as the upper 10% point of the distribution might be specified as the limiting condition because it will be economic to shorten the life of a small proportion of fuel elements rather than accept a significant reduction in output. Alternatively, if the limit is chosen to avoid a channel fire in the maximum credible transient, it is likely that the upper 1% or even 0·1% of the property distribution will be fixed as the limit. In either event, variations associated with the fuel cycle can certainly make contributions of order 10°C to the systematic component of T_{sm} and can therefore be responsible for corresponding changes of perhaps 4% in station output.

Coolant and flux distribution

Although not used in the Calder reactors, in larger but similar power reactors flux flattening is employed. For economic reasons the radius of the flattened zone will be made as large as possible because of the expected reactivity of the system. The relative coolant flow in the reactor channels is then set by gag design and subsequent pre-power adjustment with the object of securing the best output conditions consistent with the operating criteria. Generally, these gags can only be changed by withdrawing fuel from the channels in question.

Once the coolant flow pattern is set, it is almost immutable and the choice of pattern should be optimized over the life of the reactor. This is difficult because:

(*a*) At the time of decision there will be uncertainties in the initial reactivity, in the change of reactivity with irradiation, and probably in the extent of the irradiation and the type of fuel cycle.

(*b*) Although the design capacity of the heat exchange and generation equipment will be known, the design margins will be uncertain so that it may be difficult to place a value upon marginal reactor heat output.

(*c*) If the station is to be fed with all its uranium at exactly natural isotopic composition, the most flexible, and almost certainly the most economic, method of adjusting the power and coolant pattern to take account of these uncertainties is denied.

If excess reactivity is available at a given stage in the fuel cycle, this can be used by manipulation of absorber to increase the radius of the zone of flux flattening; alternatively, by a general increase in absorber addition in the flattened and unflattened zones the power distribution can be shaped to the initially chosen coolant distribution. In either case, the re-location of absorber will have to be made with due attention to the requirements of the fuel operating criteria because such movements will affect the channel to channel flux and power distribution. Where the flux is re-shaped to the initially chosen coolant distribution, there are no additional consequences except that the available reactivity has clearly been wasted. If an attempt is made to utilize this reactivity by increasing the radius of the flux flattened zone, then, because of the pre-set coolant distribution, the values of the coolant gas exit temperature or the channel T_{sm}, will rise on moving radially outwards through the unflattened zone and will reach a maximum in the outer half of the reactor. Since this peak value will not be allowed to exceed the appropriate operating criterion, the power level of the flattened zone must be reduced unless reserve blower capacity is available. In practice, faced with this limitation, the advantage of maintaining a flattened zone disappears and a less uneconomic solution can be obtained by deliberately unflattening the central zone so that the fuel operating criteria are just met both in the centre of this zone and at the peak temperature position in the unflattened region. Detailed studies suggest that there may be economic advantage to the use of available reactivity in this way.

If insufficient reactivity is available at a given stage in the fuel cycle, then the flux flattened radius must be reduced by withdrawal of absorber if the reactor is to approximate to its designed power. Under these conditions, channels in the unflattened zone have an unnecessarily high coolant flow and the restriction to reactor output via the fuel operating criteria acts in the flattened zone. Unless the shortage of reactivity is a transient effect of a duration which is short by comparison with the fuel element life-time, it will almost certainly be worthwhile to increase the available reactivity. Basically, such an increase can be obtained by reducing the average fuel irradiation or by charging fuel of higher than natural U-235 content. With the foreseeable availability and cost of slightly enriched uranium, the latter solution would be cheaper so long as the need for the extra reactivity is anticipated in time to allow enriched fuel, either as spikes or as general enrichment, to be introduced in an orderly way and without the premature withdrawal of other fuel elements. The potential merits of such a step can be appreciated from the following approximate data.

For a reactor of 150 MWe output, and of relative flattened radius 0·4, a short fall of ½% in reactivity is likely to result in a reduction of about 10% in the station output with a resulting increased cost per kWh which might be 0·05 pence. If the reactivity were restored by the use in the unflattened zone of slightly enriched uranium, the level of enrichment required would be 1·015 natural and the cost contribution approximately 0·01d/kWh. Thus, the cost of enrichment to reinstate the reactivity is likely to be very much less than the cost of doing without the reactivity. This does not mean that the reactor should have been designed with enrichment in the unflattened zone but only that a conditional optimization, given the existence of the reactor and its associated generating plant, will lead to the full utilization of this plant even if, in practice, very slight enrichment is required to maintain the reactivity. If enriched fuel additions were used in a particular design, it would probably be most convenient to make these as spikes rather than general enrichment since the number of special fuel elements to be manufactured

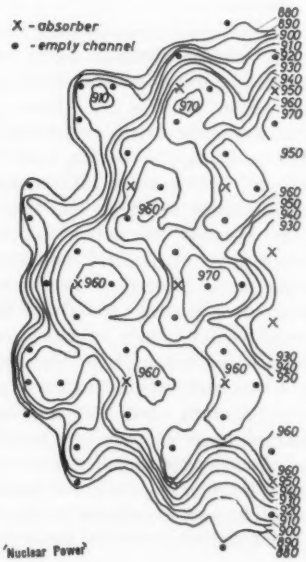
would be reduced. The consequent effects upon the channel to channel power and temperature distribution must, of course, be investigated and the safety effects of misloading considered.

Fuel element performance

The change of point reactivity with irradiation of a magnox fuel element is well known in general character, though the magnitude of the consequent average reactivity changes in a reactor under a given fuel cycle are subject to some uncertainties. Nevertheless, the broad picture is that for an equilibrium fuel cycle at 3000 MWd/t, a change of 100 MWd/t in the irradiation limit for the fuel would result in a change of about 0·1% in available reactivity. For irradiations in the neighbourhood of 3–4000 MWd/t and with current or foreseeable net fuel costs, it is cheaper to achieve the maximum burnup of the fuel which its physical endurance permits and to provide any increment of reactivity which may be required by enrichment, rather than to allow the availability of reactivity to dictate the fuel element irradiation limit.

It has not yet been possible to demonstrate that any civil design of fuel element will endure in its own reactor environment to a channel average irradiation of 3000 MWd/t, although this level is being approached by standard Calder reactor fuel. Consequently, in the short term, concern is likely to be with the physical endurance of the fuel rather than with the changes in reactivity. It is clear that this situation will persist even when the satisfactory behaviour of fuel at channel irradiations of 3–4000 MWd/t has been demonstrated.

The reasons for withdrawing fuel when the fuel cycle has been established will, therefore, be associated with fuel failure. This, in turn, implies the physical change of the fuel element to a condition where either there is a danger of an excessive CO_2-uranium reaction, or the disposition throughout the reactor of quantities of UO_2 is sufficient to invalidate the burst cartridge detection procedure. Because the number of fuel elements involved for a single reactor charge is large, the incidence of failure would be expected to show a considerable statistical element. Failure patterns which have been observed both in the UK and elsewhere, indicate that the classical distributions are applicable to fuel elements. Two systematic modes of failures have been observed in the Calder reactors with the Mark IA design of fuel element. The first takes place in the cooler elements in the channel and is associated with cavitation of the magnox. The second occurs at all points in the channel but is predominant in the No. 2 cartridge. It takes the form of bowing of the fuel in an exponentially time dependent manner so that the fins are brought closer to, and ultimately into, contact with the channel wall. Whereas the cavitation phenomenon has a widely spread distribution so that although some elements fail at 500 MWd/t channel irradiation, others survive to five or six times this irradiation. The incidence of bowing is less variable and the distribution is consequently narrower. Fortunately, it does not become a significant factor on the performance of present Calder fuel, until irradiation levels of about 2000 MWd/t have been achieved. These data are available for an early design of Calder reactor fuel because it has been possible to irradiate such fuel in experiments to levels above 2000 MWd/t. In fact, the data available are of indirect value only in fuel cycle analysis for civil reactors because steps have been taken to eliminate or delay the onset of both of these modes of failure.



Predicted fine flux distribution in the flattened zone of a typical civil reactor (Fig. 1)

For this reason it is most desirable to have irradiation trials on any new design of fuel element which departs significantly from those from which experience is already available. It would be advantageous, though it is not necessarily economic, to conduct such trials on a large scale so that the detailed life distribution to failure can be determined for each type of fuel element. In practice, trials are likely to be restricted to 10–100 channels of fuel. While the main modes of failure may be detected under these conditions so long as the testing environment in the Calder or Chapelcross reactors can be made sufficiently similar to the intended environment of the civil reactor, abnormal modes of failure occurring perhaps one in 10,000 times will not be detected. This is unimportant so long as these odd failures are not sufficiently catastrophic to merit special attention. It is also necessary, because existing reactors will not in general duplicate the environmental conditions of a new reactor design, to undertake some endurance testing out-of-pile in rigs or loops where, for example, the creep or deformation of fuel element components and heat transfer surfaces under aerodynamic forces can be studied. If the laws of deformation involved are sufficiently well understood it may even be possible to undertake and interpret accelerated creep or distortion tests in such rigs. Finally, but most importantly, the fuel withdrawn from a reactor during the life of the first charge, and to a lesser extent of subsequent charges, will be sampled and a fraction of it subjected to physical and metallurgical examination. This will indicate the development of characteristics such as growth, swelling or deformation which could ultimately lead to failure. In the early civil stations, a proportion of the fuel loaded has been the subject of special measurements so that on discharge it can be used as a part of this monitoring programme.

The objective of these various studies is to provide two classes of information; (a) it is necessary to obtain an estimate of the life to failure distribution for those modes of failure which are of relevance; (b) it is also important to know the nature of the failure when it develops and, in particular, the time which is likely to elapse between the detection of the failure and its becoming an embarrassment to the reactor

operator. With cavitation failures in the Calder reactors, for example, the doubling time of burst cartridge detection gear signals has been about a month. Since a period corresponding to several doubles could be tolerated by the fuel without significant oxidation of the uranium, or any other embarrassing manifestation, it has been practicable to operate for long periods with a number of incipient fuel failures in the reactor. The problem would have been further simplified if continuous charge discharge operations had been possible and it is credible that with experience, a civil reactor operator might tolerate a high proportion of cavitation failures before withdrawing his fuel. If this were the first significant mode of fuel failure, a willingness to accept, for example, 25% cavitation failures rather than 1% cavitation failures in discharge fuel might permit an increase in fuel element irradiation lifetime of several hundred MWd/t. The reactor operator would also be willing under these conditions to have a queue of a small number of cavitation failures awaiting discharge. If, however, there were a systematic mode of failure which developed very rapidly after detection, it might be that the charge/discharge machinery already deployed on the handling of an unfailed channel below a different standpipe could not be re-deployed to remove the failure in less time than that in which the failed fuel element became a hazard to the reactor. With such a failure it would clearly be necessary to shut down the reactor until the element could be withdrawn, This, in turn, would lead to the loss of the station generating capacity for a period of perhaps 24 hours. If a systematic mode of failure of this type were present in fuel elements, then the choice of the irradiation life time would clearly have to be made so as to make it improbable that such failures would occur. Although a small number of rapidly developing failures have been observed in the Calder and Chapelcross reactors, such failures are not systematic and have occurred in a very small proportion of the fuel. Furthermore, means have now been found of detecting them before they mature.

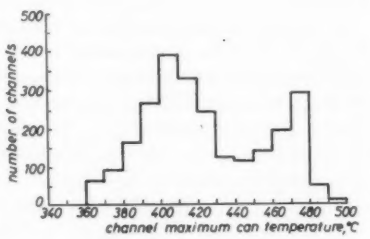
Charge/discharge machinery capacity

The possibility of adopting various types of fuel cycle in a reactor depends amongst other things upon the capacity of the charge/discharge machinery. For a given design performance, the actual capacity is likely to be influenced by two main factors. Firstly, the reliability and availability of the machinery, and secondly, the pattern of the fuel handling operations.

This latter dependence arises because the operation of replacing fuel in a channel consists of several parts, some of which relate to the channel and others to the pressure vessel standpipe which is common to many channels. Consequently, there will usually be economies in time if, for one set of operations on the standpipe, the fuel in several channels is replaced. The effective capacity of the charge/discharge machine is thereby increased. If this mode of operation is exploited so as to discharge, for example, eight channels at a single visit, then the channel to channel flux and power distribution may be disturbed by several per cent as a consequence of the replacement of a cluster of channels with new fuel of different nuclear properties. Because of the importance of the fuel operating criteria in determining the station output, such a procedure may, in fact, result in a corresponding loss of output. It is, therefore, necessary to weigh the relative advantages of higher machine rates against a possible loss in station output in assessing the machine performance upon which dependence can be placed in selecting a fuel cycle.

The importance of the pattern and nature of the fuel element failure modes has already been mentioned. The time which is taken to discharge a failure after its existence becomes known, but when the charge/discharge machinery is deployed elsewhere on the reactor, is an important item in the attitude of the reactor operator to the development of failures and, therefore, to the selection of a fuel irradiation limit and a fuel cycle. There is the additional problem that failed fuel may be subjected to a different handling procedure after its discharge from the reactor, either to avoid contamination of fuel handling equipment or to segregate the elements in question so that they may be subjected to subsequent examination without pond corrosion. The special handling procedures may sterilize a set of fuel handling machinery for a long period of time so that the effective capacity of the charge/discharge machinery may depend, amongst other things, upon the proportion of failures which the operator is prepared to tolerate in his fuel cycle.

Predicted histogram of channel maximum can temperature for a typical civil reactor (Fig. 2)



'Nuclear Power'

Experience with the Calder and Chapelcross reactors suggests that the problem of matching power and coolant distributions is sufficiently difficult to make the operator prefer to achieve whatever simplifications are possible by maintaining the maximum degree of symmetry in his reactor core. For this reason, it is likely that quadrantal symmetry, at least, will be sought and this must be taken into account in assessing the fuel handling capacity. It is not yet clear in a fuel cycle where a significant proportion of fuel failures were tolerated, whether it would be desirable to maintain symmetry by discharging all images of the failed channel to maintain this symmetry.

In a practical fuel cycle study, a nominal fuel handling capacity will be specified based, if possible, upon early experience of the operation of the reactor. When the main parameters of the fuel cycle have been decided, a detailed operational study of the fuel handling operations must be made, involving the writing out of channel by channel sequences. These must take account of the number of charge/discharge machines available at the reactor and also of any possible interaction between machines whereby standpipes may be rendered inaccessible by the presence of a machine on an adjacent or nearby standpipe. One solution, considered at Berkeley, has been to write out a series of standard ' walks ' which a fuelling machine on the pile takes between various standpipes. The walks themselves were so chosen that each, when completed, maintained symmetry of the core loading, and that simultaneous walks could be performed by more than one machine without interaction and without interference if one of the machines encountered special difficulties in a particular discharge operation. Clearly, there will be a set of such walks which allow all standpipes to be visited and which can be so combined as to allow stand-

pipe visits to be made with a frequency appropriate to the chosen fuel cycle and to the rating of the fuel in the channels below a particular standpipe. This system has many advantages. But it suffers from relative inflexibility should a significant number of discharges of fuel be occasioned by random events such as fuel element failures. An alternative approach has been to place each channel or group of channels in a sequence for discharge according to the chosen fuel cycle; then an index of urgency has been constructed so that at any given time, the next channel or group of channels to be withdrawn are those which have the greatest urgency index. This latter method may be somewhat less efficient in fuel utilization but has the advantage that discharges introduced by, e.g., fuel element failure or machine break-down, can be incorporated in the system without disrupting the chosen charge/discharge sequence.

Another detailed problem associated with the fuel discharge operations is the decision as to whether, when a standpipe is visited to withdraw a channel containing a failed fuel element, other channels nearing their irradiation limit should also be withdrawn. Such a procedure results in a reduction in fuel utilization but minimizes the effect on the fuel handling capacity of random failures. Accordingly, the procedure adopted and the critical level above which unfailed channels would be withdrawn is a function of the available charge/discharge capacity in relation to the required fuel cycle and fuel handling programme.

The fuel machinery, in addition, to performing the charge/discharge operations could be required to change the position of fuel within the reactor core. It is well known, for example, that the reactivity life time of fuel can be improved either by a push through or an axial inversion scheme. It is also known that by radial interchange of fuel channels during the life of the first charge, the utilization of the first charge during a period when an equilibrium age distribution is being developed can be improved. It does not appear probable in the immediate future that axial shuffling will be adopted because it may have effects which cost more in terms of fuel life time than the savings gained by increasing the available reactivity. The matter is under test in the Chapelcross reactors. This objection does not apply to the radial interchange scheme. This could credibly be adopted if experience showed that the fuel handling machinery at a particular station had the capacity to perform these operations in addition to its normal duties, and that the operations could be carried out without significant mechanical handling damage to the fuel elements themselves.

Some evidence on the handling of irradiated fuel has been provided from Calder where fuel in more than 200 channels has been multiple-handled within the reactor after many months irradiation. These operations were undertaken with the reactor shut down; in subsequent irradiation, only one fuel element gave an indication of handling damage.

TYPES OF ANALYSIS

Fuel logistics

The direct effect of changing a fuel cycle is to change the rate of fuel purchase and resale. The arithmetic of fuel requirements for various cycles is easily undertaken and provides a first index of the relative merits of various schemes. In converting these figures to a financial argument a number of points must be considered:

(*a*) The fuel life time is likely to be several years. Equal quantities of fuel in the first and subsequent fuel charges will, therefore, have different effective values due to the discounted interest charges for the later fuel and because the trend of costs for uranium concentrate is likely to be downwards for the next few years.

(*b*) The price of magnox fuel elements will contain a component of fixed costs. In assessing the relative merits of different cycles, the real cost of increments of production should be employed.

(*c*) The requirement for replacement fuel, even in a 1000 MWe station, is a good deal less than the economic rate of manufacture. There may be a need for campaign production with associated stocks subject to interest charges and obsolescence risks. (This would be a considerable problem if, for example, off-load charging during the summer were applied to all the UK magnox reactors.)

The same figures for fuel throughput will also be checked against the nominal fuel handling capacity of the machinery pending more detailed studies.

Reactivity and power

The problem of selecting and maintaining coolant and power profiles in the reactor have been sketched under a previous heading. For assessments, it is customary to divide the core into perhaps 10 radial zones. From the fuel cycle arithmetic, the distribution of irradiation age in each zone is determined and the zone reactivity is deduced. In turn, the radial Laplacian and the radial component of the flux distribution are deduced. The pre-set coolant profile can then be used to determine the coolant gas exit conditions at various coolant flows. These calculations, together with a knowledge of the blower characteristics and the performance characteristics of the steam and electrical generating plant make it possible to study time changes in output for various forms of fuel cycle. Such studies are only approximate because they do not take account of channel to channel differences or of the fuel operating criterion as it would be applied in practice, but they can be used for comparative purposes.

Detailed flux and temperature studies

When a particular fuel cycle is chosen and put into operation, it is necessary to make inferences from fuel temperature measurements in perhaps 5% of the channels and gas outlet temperatures in another 10% of the channels, about the distribution of temperature and power in all the unmonitored channels. The inference is required to ensure that the operating criteria for the reactor are being satisfied and also to secure best deployment of absorber additions.

A model has been developed and incorporated in computer programmes for making the calculations on which the above inference is based. The method has been used for studying various absorber patterns in the Calder and Chapelcross reactors and has been refined to take account of the irradiation dependent changes in the fuel. It is presently being used to examine problems of absorber and temperature distribution for the Bradwell and Berkeley reactors.

The type of result obtained from this work is illustrated in Figs. 1 and 2. The first of these shows the estimated thermal flux channel by channel in the flattened zone of a typical civil reactor as predicted by a two group finite difference programme and the second shows a histogram for the systematic component of variation of T_{sm} over the whole core. If experience in the Calder reactors is parallelled in civil stations, the model will be further refined when measurements of fuel and gas temperatures are available from these stations to compare with predictions.

to be continued.

The design for the National Bureau of Standards tank-type 10 MW high flux research reactor is nearing completion. It will be used by the Bureau at its new site at Gaithersburg, Maryland, to establish precision measurement techniques and to study basic properties of matter

The NBS High Flux Reactor Design

THE NATIONAL Bureau of Standards has already developed a low-intensity neutron standard which is used as a reference. This new high flux reactor, to be known as NBSR, will enable work to be extended to the measurement of high-intensity fluxes. Facilities include special converter fuel elements for in-pile irradiations and a cold neutron facility. Other Government agencies in the Washington area will be able to use the reactor.

Reactor

The reactor is a tank type, heavy water moderated and cooled, fuelled with enriched uranium and similar to the CP-5 at Argonne. The initial power level is 10 MW but this could be increased to 20–25 MW with additional heat exchangers and cooling towers. The core will have 24 fuel assemblies of U/Al alloy fuel, clad in aluminium. Each assembly consists of 17 MTR type plates which have two active portions separated by a dummy aluminium section. The complete assembly is cooled throughout its length. This element design reduces the fast neutron and gamma ray flux from the horizontal beam ports at the core centre line.

Fast neutron irradiations will be provided by special converter fuel elements.

Research work

The reactor will be used to provide reliable precision measurement techniques for both high and low intensity neutron fluxes. The Bureau says that the most significant function of the NBSR will be the study of basic material problems. Neutron diffraction techniques will be used for work on atomic and nuclear structure. Some of the particular areas of work will be examination of magnetic crystal properties, location of hydrogen atoms, intermolecular force constants and chemical bond strength. Effects of radiation and the use of radiation processing techniques will also be examined.

Other areas of research it is proposed to cover are activation analysis and the study of fission processes. Radioisotopes will be made in the reactor and tracer elements will be provided for a variety of transfer problems such as diffusion, phase transformation, exchange and complex flow.

One of the special converter elements will be used with cryogenic equipment for irradiations at near liquid helium temperatures.

The Bureau is also planning the use of a cold neutron moderator to provide a low energy neutron energy flux for examining crystal lattice vibrations and other long-range problems. This will be examined experimentally before the final design is completed.

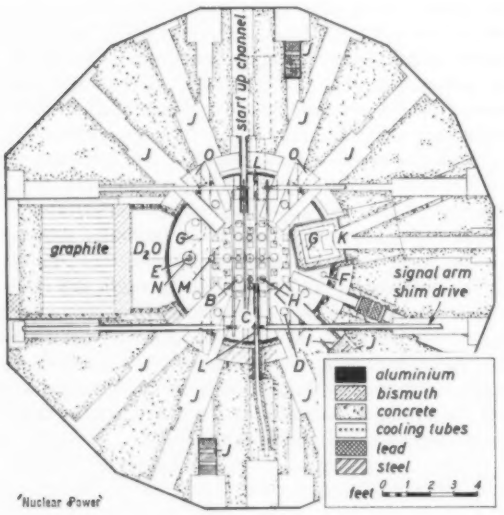
The reactor will be complemented by cold, warm and hot laboratories. These will provide a complete range of maintenance and examination facilities.

REACTOR DATA

Operating level	10 MW
In-pile flux	10^{14} n/cm² s
Fuel (MTR type, 24 assemblies)	U/Al alloy
Cladding	Aluminium
Moderator	D_2O

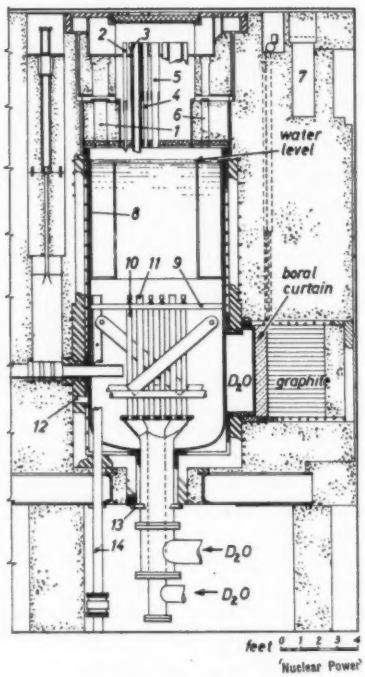
FACILITIES

7	*4-in vertical experimental facilities or converter tubes*
4	*2·5-in vertical experimental facilities*
11	*horizontal facilities*
1	*cold neutron facility*
4	*rabbit tubes*



Plan of the reactor

A MTR type fuel element (24); **B** 4-in experimental facility or converter tube (7); **C** 2·5-in experimental facility (4); **D** 4-in experimental thimble (7); **E** transfer chute; **F** over-flow pipe; **G** outlet pipe (2); **H** fine control rod; **I** beam port gas seal; **J** vertical shutter (11); **K** cold neutron facility; **L** rabbit tube (4); **M** transfer tool; **N** pick-up tool; **O** full power level penetration (4)



Elevation section of the reactor

1 access and removal port for signal arm shim safety rods (4); **2** fuel element pick-up tool, 1 required for each element; **3** fuel element transfer tool and port for 4-in expt. thimble (6); **4** 2·5-in vertical thimble port (4); **5** central converter tube port; **6** expt. vertical thimble port (5); **7** outer emergency cooling tank; **8** inner emergency cooling tank; **9** fuel element hold down grid plate; **10** fuel element; **11** expt. facility; **12** power level control port (4); **13** gas seal; **14** fuel element transfer chute

Points from Papers

reports, meetings, conferences

WATER REACTOR STABILITY

Part of the US AEC study on the transient behaviour of heterogenous water reactors, and supplementing reactor experiments in SPERT IA, are the out-of-pile reactor experimental studies being conducted by Space Technology Laboratories. Reporting work completed in 1960, data is presented clarifying the role of steam void formation in reactor shutdown using an electrically heated insulated fuel plate. Present indications are that for faster periods, steam void becomes the dominant shutoff mechanism, even for relatively high void coefficients. In an analysis of the power-void transfer function a possible relationship has appeared between the transfer function and some types of hydrodynamic instabilities.

Kinetic studies of heterogenous water reactors. Space Technology Laboratories, Inc. **Report RWD-RL-190.** 129 pp. Available from OTS, Department of Commerce, Washington, $2.75.

PULSED REACTOR FACILITY

The Sandia Pulsed Reactor Facility is specifically designed for radiation effects experiments requiring an intense pulsed source of fast neutrons and gamma rays. It is designed around the SPR, a descendant of the LASL Godiva I, and consisting of a bare metal reactor with six individual automatic scram devices, including duplicate period scrams, for the delayed-critical sequences. A standard burst of 2×10^{16} fissions is planned with a 50 μs pulse width at half maximum, 3×10^{16} leakage neutrons per burst, and a 3×10^{20} n/s peak leakage rate.

The Sandia Pulsed Reactor Facility (SPRF). J. L. Colp and P. D. O'Brien. Sandia Corporation. **Report SCR-229.** 18 pp.

SODIUM HEAT EXCHANGERS

The US AEC has made conceptual design studies, as part of its more detailed research and development programme, of a sodium-to-sodium intermediate heat exchanger and a sodium-to-water steam generator. Experimental units scaled down to 30 MW are now to be built. The heat exchanger design selected is a vertical, counterflow, shell-and-tube type with disk and doughnut baffles. To operate at a design pressure of 100 lbf/in²g, the inlet and outlet temperatures of the primary sodium circuit are 1200°F and 700 to 900°F respectively. Those of the secondary sodium circuit are 775°F and 1140 to 1175°F. Type 316 ss is to be used for the structural members, Type 304 ss has been chosen for the internal parts. The steam generator has a design pressure of 2500 lbf/in² on the water side and 100 lbf/in² for the sodium side. The concept selected is a shell-and-tube type made up of a boiler and steam drum, to be constructed from 2¼% Cr 1% Mo steel, and a superheater section, constructed of Type 316 ss with the water side overlaid with Inconel for steam-corrosion protection.

Design of reliable and economical heat exchangers for high temperature sodium service. R. D. Seifert and L. E. Phillips. Alco Products. **Paper 61-SA-41.** Read at the ASME Summer Annual Meeting, Los Angeles, June, 1961. 11 pp.

HIGH TEMPERATURE GAS PROBE

A heat flux probe for measuring rapid fluctuations over a wide range of temperatures has been developed which has a response time ~250 μs and is capable of withstanding gas temperatures >3000°C at atmospheric pressure. The probe is similar in operation to the hot wire anemometer with constant temperature compensation, the wire being replaced by a glass tube 0·15 mm o.d. and 0·10 mm i.d. with a platinum coating of about 1000 A thick. The sensing element is internally cooled by water, the cooling rate of which limits the maximum heat flux to around 300 cal/cm²s. Changes in heat transfer between the element and the environment are directly determined from the changes in power supplied by the compensating circuitry. Velocity effects are controlled by mounting the sensing element in a sonic flow aspirating probe.

Heat flux probe for dynamic measurements in high temperature gases. L. M. Fingerson and P. L. Blackshear. University of Minnesota. **Technical Report 61-2.** 30 pp. March 1961.

SINTERED ALUMINIUM TESTS

As part of the Danish AEC study on canning materials for the organic cooled, heavy water moderated reactor, detailed heat treatment studies have been made on sintered aluminium products (SAP). It was seen that SAP alloys form blisters when heated in air at above 610°C and that in the unstressed condition fissures form in the microstructure at 500°C, due possibly to the hydrogen content in the material. These tendencies varied at random between the material types, shapes and batches. SAP was however stabilized after vacuum treatment at 600°C for 4–120 h, after which no blisters or fissures formed when subsequently heated in air. Gas analyses indicated that the hydrogen content had been reduced to ≃10 p.p.m.

The effect of heat treatments on the structural stability of sintered aluminium products. N. Hansen and E. Adolph. Danish AEC. **Risö Report 25.** 39 pp. May 1961.

ZIRCALOY CREEP TESTS

Related to the present designs for NPD-2 and CANDU, creep tests have been carried out on longitudinal samples from two zircaloy-2 pressure tubes at 300°C and at stresses between 13,500 lbf/in² and the ultimate tensile strength. Many of the tests were continued beyond 5000 h. It was seen that the requirement of a creep rate of 10^{-5}%/h is met at a stress of 30,000 lbf/in² at 300°C, and under these conditions the rupture life is over 10 years. The stress-rupture requirement, 4/5 of the stress that will cause failure in 100,000 h, was met at 24,000 lbf/in². The tests also indicated that the difference in stress to produce a certain creep rate for cold-worked zircaloy-2 from different sources remained constant as the creep rate goes down. It is approximately the same as the difference in ultimate tensile strength at the creep-testing temperature.

Creep of Zircaloy-2 pressure tubes: 1. longitudinal direction. L. G. Bell. Atomic Energy of Canada Ltd. **Report AECL-1289.** 45 pp. June 1961.

New Reports

Thermal conductivity determinations on uranium dioxide by a radial flow method. V. C. Howard and T. F. Gulvin. UKAEA Risley. **IG Report 51 (RD/C).** 22 pp. Available from HMSO 3*s*.

The effect of non-tensioned steel in prestressed concrete. P. W. Abeles. 'The Reinforced Concrete Review', **5** (10), June 1961, pp. 635-642.

Neutron cross sections in zirconium, April 1961. R. Sher. Brookhaven National Laboratory. **Report 666 (T-220-40-1).** 12 pp. Available from Depository Library.

Neutron cross section Evaluation Group Newsletter No. 4. May, 1961. R. Sher and S. Moore. Brookhaven National Laboratory. **Report BNL 672 (N-4).** 7 pp. Available at Depository Libraries.

Compact reactor development for ground nuclear power applications. M. A. Rosen, T. W. McIntosh and R. A. Duval. US AEC. **ASME paper 61-SA-42,** Summer Annual Meeting, June, 1961.

Seminar on the Physics of Fast and Intermediate Reactors. Abstracts of papers. Vienna, 3-11 August, 1961. International Atomic Energy Agency. **Publication SM-18.**

Physical properties of Santowax 'R' for heat transfer calculations (AERE R/M 183 revised). R. W. Bowring, D. A. Garton and J. H. Kinneir. UKAEA Winfrith. **Report AEEW-M118.** 39 pp. Available from HMSO 7s.

Data requirements for the 1960| version of STAB. A. R. Curtis, J. G. Tyror, and H. E. Wrigley. AERE Harwell. **Report AERE-M898.** 27 pp. Available from HMSO. 4s.

Effect of pile radiation on the carbon dioxide-graphite reaction. P. C. Davidge and W. R. Marsh. AERE Harwell. **Report AERE-R3706.** 49 pp. Available from HMSO 7s.

Activity of irradiated uranium fuel specimens at times greater than 10 hours after irradiation. I. S. McGill. UKAEA Risley. **Report DEG 351(D)** 14 pp. Available from HMSO 3s.

'Nuclear Power' INFORMATION

The papers reviewed here represent only a very small selection of those acquired and read by *Nuclear Power*. If you hear of a paper and have difficulty in obtaining a copy, write or telephone *Nuclear Power* Information Bureau, 77-79 Charlotte Street, London W1, MUSeum 8252.

New Product Survey

EQUIPMENT · INSTRUMENTS · MATERIALS

METAL RING SEALS

static and dynamic uses

Aero Controls claim that the Wiggins 'Bar-X' all-metal ring seals which they are marketing represent a revolutionary development and solve a wide range of static and dynamic sealing problems for hydraulic, pneumatic and hot gas systems

The Wiggins 'Bar-X' all-metal seals are claimed to be indifferent to temperature variations and resistant to nuclear radiation

in valves, actuators and fittings, provided that operating temperatures and pressures are within the general range —455°F to 1200°F and 0 to 6000 lbf/in² respectively. They are available in a variety of finishes such as tungsten cobalt, tungsten carbide, nickel-chromium, silver and gold, etc.

The range extends from ½ in i.d. to any size required, with standard seals up to 3 in for static applications and up to 2 in for dynamic applications. Suitable for use with a very wide range of materials they may be stacked in series or parallel as required. The seal, which is geometrically stable, is unaffected by direction of motion or pressure and is not sensitive to extreme changes of pressure. Experience indicates that with use the seal is self-cleaning on sliding surfaces, the sealing efficiency curve showing a rise.

★ 208

NEW THERMOCOUPLES

high temperature use

Thermocouples for detecting temperatures of up to 4200°F, using combinations of tungsten, rhenium, rhodium, molybdenum, iridium and platinum, are to be marketed by Honeywell Controls. Types are available for both oxidizing and reducing environments.

The maximum of 4200°F is obtained by using tungsten/tungsten 26%–rhenium. Thermoelectric output in this type is nearly three times that of the tungsten-rhenium thermocouple which it will largely supersede. The temperature e.m.f. curve is more linear in the 2000–4000°F range. Improved uniformity of wire is due to the 26% alloy being more homogeneous.

Another thermocouple, for continuous use up to 2732°F and intermittent service up to 3272°F, uses platinum 30%-rhodium/platinum 6%–rhodium. The new alloy type does not suffer excessive grain growth, vaporization, contamination and other disadvantages inherent in existing platinum rhodium thermocouples.

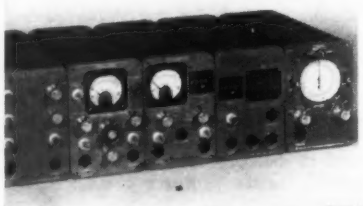
★ 209

NUCLEONIC INSTRUMENTS

new transistorized series

In conjunction with the UK AWRE, Nuclear Enterprises has produced a series of transistorized and printed circuit nucleonic instruments of uniform dimensions, 4 in wide × 6 in high × 10 in deep, suitable for a variety of combinations. Four units can be fitted side-by-side on a shelf in a standard 19 in rack. All connexions are made through the front panel.

The amplifier, NE 5252, has an overall voltage amplification of 1000 times with a preamplifier stage for high input impedance and three amplifier stages each with ten times amplification. The analyser, NE 5152, is capable of accepting random pulses at a rate of ≃30,000 pulses/s. The channel width can be varied in 0·2 V steps from 0·2 V to 1·0 V; the total range of the pulse amplitude level control is 10 V. The



Nuclear Enterprises' new series of unitized transistorized nucleonic instruments, left to right: pulse amplifier, analyser, ratemeter, scaler, timer

amplitude level may be swept either manually, by a sweep recorder, or by an internal sweep circuit.

The ratemeter unit, NE 5452, suitable for all commercial recorders and oscilloscope display, has a maximum counting rate of 30,000 pulses/s in eight ranges. Below 10 c/s pulses are counted on an electro-mechanical register, with count rate indicated on a meter. With a resolving time of 1 μs, the scaler NE 5072 can store 10^9 counts. Display is by neon bulbs up to 10^5 with the remaining four digits on an electro-mechanical register. Except for the register, remote control of counting time and resetting is possible.

In the timer, NE 5052, pulses are produced at half-second intervals by a stopwatch and elapsed times from 5–20,000s may be selected. Time loss is 3 ms. The power unit, with an input of 240 V, 50–60 c/s, supplies both the L.T., 20 V at 750 mA, and the E.H.T., 500–1500 V at 3 mA or 1000–3000 V at 1 mA.

★ 210

LINEAR AMPLIFIER

plug-in accessories

Hamner's basic amplifier unit, based on the Oak Ridge A–8 design, has been repackaged to allow for a number of

The Hamner N-338 amplifier with pulse height analyser and integral discriminator

optional plug-in accessories. To the N–308 may be added, if desired, an integral discriminator of the PR Bell design, a single channel pulse height analyzer of the Fairstein design, or both pulse height analyzer and integral discriminator. When these options are added, model numbers become N–318, N–338 respectively. The additions are of the plug-in type and may be added at the time of purchase or later.

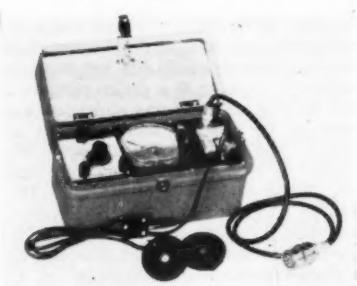
In addition to any of the pulse analyzing sections, the user may incorporate a special pulse cross-over pick-off gate for coincidence work in the 30 μs range. This latter accessory, N–670, is also of the plug-in type. Each unit is equipped with a rack-mounted centrifugal blower and dust filter.

★ 211

MEASURING THICKNESS

portable ultrasonic gauge

The new Dawe transistor ultrasonic thickness gauge, Type 1103, has a range



The new Dawe 1103 thickness gauge is battery operated and can be used in awkward locations

of 0·09 to 5 in and is suitable for rapid and simple thickness measurement in awkward locations and where there is access to one side only. Applications include corrosion studies and flaw detection on piping, tanks and pressure vessels.

The material selector switch gives immediate readings with steel, aluminium and copper. Other metals, glass, plastics and ceramics can be tested by using the undesignated switch position and calibrating on a known thickness of the same material. Accuracy is 3–5% of the wall thickness provided that the surfaces are clean and flat.

The unit consists of a transistorized oscillator, generating waves at frequencies variable between 2 and 4 Mc/s, and a piezo-electric transducer. Resonant frequencies are directly related to the thickness and are found by noting the accompanying increases in the headphone audio signal and in the output meter deflexion. For flat, cylindrical and compound curved surfaces down to 2 in o.d. or 12 in i.d. the standard flat surface transducer is used. Concave transducers are available for use on smaller convex surfaces.

★ 212

FLEXIBLE PIPES

glass fibre and resin

Suitable for handling effluents and corrosive liquids, the 'Epoch Pipe' introduced by Bristol Plastics is manufactured from high strength glass and acrylic fibres and thermo-setting epoxide resin to give a high degree of corrosion resistance. During fabrication, resin impregnated glass fibre is wound on to pre-heated mandrels resulting in an extremely smooth pipe bore. This smooth

The mirror-smooth bore of Bristol Plastics' 'Epoch Pipe' prevents build-up of deposits and ensures good flow characteristics

bore combined with corrosion resistance prevents build-up of internal wall deposits and cuts frictional losses.

Pipes and fittings are made in sizes from 4 in to 15¼ in bore, a range that is to be extended to 6 ft dia. It is claimed that they are as strong as steel pressure-pipes, are one quarter the weight and ten times more flexible, making them suitable for laying over rough ground. Two ranges are available: Series A for operating pressures of 100 lbf/in² and over, Series B for systems up to 100 lbf/in².

Although listed to operate at pressures up to 600 lbf/in², 'Epoch Pipe' can be made to operate under unlimited pressure; all pipes and fittings being tested to twice their operating pressure before despatch. The system is supplied for continuous operation in three temperature ranges: 0–60°C, 60–90°C and 90–120°C. In certain low pressure applications the system can be used up to 140°C.

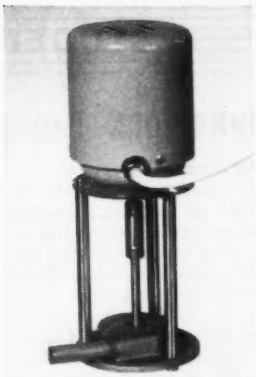
★ 213

IMPELLER PUMPS

laboratory applications

Small stainless steel a.c. pumps suitable for laboratory use at temperatures from —20°C to 110°C have been introduced by Jones and Stevens. Type P.30, weighing 22 oz, gives a flow of 2½ pint/min to a head of 4 ft of water; Type P.50, weighing 27 oz, gives a flow of 5 pint/min to a head of 4 ft 6 in.

The small motor driving the impeller is a single phase squirrel-cage induction type of either 30 or 40 W. The length of the



The new stainless steel a.c. pumps from Jones and Stevens should find many laboratory applications

pump drive can be made to order to provide a maximum immersion of 6½ in of water.

★ 214

IN BRIEF

• **Digital voltmeter.** Automatic ranging and polarity, 500 ms balance time, and silent reed relays have been combined in Cubic Corporation's new V–71 DC voltmeter. It covers the full d.c. range from 1mV to 999·9 V, and includes a built-in safety circuit.

★ 215

• **Induction heaters.** Delapena have introduced three new 150 kc/s radiofrequency induction heaters. The E75 and E100 have continuous output ratings of 75 and 100 kW respectively; the E75/100, with a continuous output of 75 kW, has the additional facility of intermittent operation at up to 100 kW with 1 min stand-by intervals, so long as the average output does not exceed 75 kW.

★ 216

• **Ionization chamber.** Plessey Nucleonics' new ionization chamber PNI 1091 enables response to gamma radiation to be made level down to V100 keV, below which level it drops sharply. The chamber can also be made sensitive to thermal neutrons, and with appropriate filling provides approximate tissue equivalence to fast neutrons over a wide energy range.

★ 217

• **Temperature control.** A new mercury-in-steel, on-off temperature controller, with independent circuits for control at any two points, has been produced by British Rototherm. Temperature ranges are available between —20°F to 1000°F.

★ 218

• **Subminiature diodes.** Twenty-four new types of subminiature glass zener diode with a voltage range of 3·3 to 27 V have been introduced by International Rectifier. Rated at 250 mW power dissipation, they provide high stability and excellent voltage regulation over the range —55°C to 130°C.

★ 219

• **Silicone resin.** One serious limitation of cement-bonded asbestos board in its use as a heat resistant electrical insulating material is its high rate of water absorption and consequent loss of insulating properties. This can now be overcome by impregnating the board with a new resin, DP 2728, recently developed by Midland Silicones.

★ 220

• **Electrical connexions.** Sealectro's solderless wire connexions can now be fitted to their FT–WJ–100 feedthrough terminal. This is rectangular in shape, with truncated circular ends. The terminal fits into a rectangular shape punched into the chassis.

★ 221

• **Permanent magnets.** From Johnson Matthey comes the latest development in magnetic alloys of the cobalt-platinum system, Platinax II. With a BH $_{(max)}$ of $9{\cdot}2 \times 10^6$ gauss-oersteds it is one of the most powerful permanent magnet materials known. Before its final heat treatment it can be rolled, drawn, or machined without difficulty.

★ 222

• **Metal spraying.** Adding little extra weight to their Mark 33 metal spraying pistol, Metallisation have produced an auxiliary spreader nozzle attachment which will spread the spray stream from a $\frac{3}{16}$ in dia. wire to an effective width of 3 in at normal spraying distance.

★ 223

• **Boron silicide.** Allis-Chalmers have announced the development of a 70% boron silicide that can be used at 1400°C in air for extended periods. It can be fabricated by conventional powder metallurgical and ceramic techniques and it has good oxidation and thermal shock resistance properties.

★ 224

• **Wall coating.** Versalloid, a self-baking polyester resin marketed by Lloyds Packing Warehouses, may be applied to masonry, concrete, plaster, cement, asbestos, etc. It penetrates and densifies these porous surfaces forming a permanent, non-porous, waterproof seal that will not crack, flake, chip, peel or, craze. Excellent resistance to water, chemicals, etc. is claimed.

★ 225

★ *For further information on any item, circle the appropriate number on the reply card facing page* 106.

STUDENTS' NOTEBOOK

GROUNDWORK—Teaching

2—The training of operations staff for the civil nuclear power stations

Fulfilment of the UK's nuclear power programme has created an urgent requirement for the adequate training both of the CEGB's senior operations staff and of the commissioning teams from the consortia building the nuclear power stations. Some of the earlier staff from the Generating Board attended the 16 weeks Harwell course but, in the majority of cases, the 6 weeks pre-Harwell course held at the Advanced Colleges of Technology (see August issue, page 90), and the special introductory course at the Bristol College of Science and Technology, is now considered adequate as a prerequisite to the Calder Operation School course run by the UKAEA at Calder Hall.

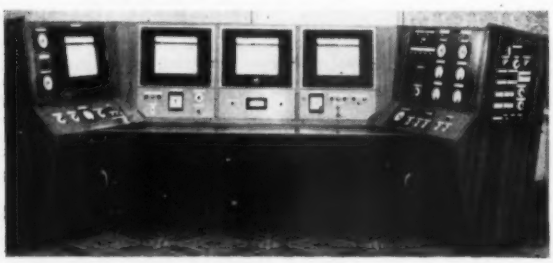
Over 600 students have passed through this school, including the station superintendents, the shift charge engineers, the assistant charge engineers and the assistant engineers (operation) of the first four civil nuclear power stations, together with members of the commissioning teams. Some 40% of the students come from abroad, many of them from Latina and Tokai Mura. The bulk of the course consists of lectures by the school's three full-time lecturers, supported by experts from the various Calder departments, and backed up by visits and surveys of the power station and by the use of a simulator, which is an exact replica of the Calder Hall control console.

Students are encouraged to use the simulator with or without supervision throughout the course to get a good appreciation of the response of the reactor under a variety of different conditions. A second simulator, designed by the AEA and under construction by Shorts, is shortly to be installed. Containing 200 computing amplifiers it will incorporate the special characteristics of the large civil stations, especially those associated with a multi-zone automatic control system. It will also be possible to simulate turbine faults, grid frequency, variations, steam mains disturbances, blower faults, etc.

Much of the course is devoted to the technology of the Calder stations. During the last week, however, the civil power stations are discussed, with emphasis on the important differences between these stations and Calder Hall. The lecturers, from the Industrial Power Branch, have all been involved in the specifications for these new stations. The facilities required to support a nuclear power programme are demonstrated by visits to the fuel element manufacturing plant at Springfields and to the reprocessing and plutonium extraction plant at Windscale. In a number of cases, senior CEGB staff and consortia commissioning engineers, return to Calder Hall on attachment for two months or more.

CEGB operating staff also attend for a period of two weeks the Berkeley Reactor Training School where the emphasis is on practical operational problems relating to the civil stations. The main facility is the simulator that aids the appreciation of the characteristics of the subcritical, critical and supercritical reactor. Exercises include bringing the reactor up to full power with positive or negative temperature coefficients of reactivity. Account is taken of the contribution of the control rod, graphite, fuel and xenon to reactivity balances.

Trip units are provided to shut down the reactor in the event of excess flux, short doubling time, high fuel element temperature, or high flux (or power) on the low level channel. The circuits provide simulation of one boiler completely, the signals obtained being taken as representative of conditions in a group of five boilers. A second panel represents boiler no. 6 on which various faults are simulated such as feedwater supply failure and the sudden blower failure. Separate integrating amplifiers allow the simulation of the H.P. and L.P. steam valves, for each turbine, including the effects of sudden closure. It is expected that operational staff will return to the school again for future refresher courses.



Built by Elliotts, Berkeley's reactor simulator represents the control desk of a typical CEGB nuclear power station. Indicators and recorders (left and centre) display the control rod position, reactor power level, power deviation, doubling time, coolant flow and fuel element temperature. On the right is the turbo - generator control panel. To the extreme right are controls for introducing reactor fault conditions and disturbances.

NEWS

• A new approach to the teaching of electrical machine theory has been adopted at the Queen Mary College. To fulfil the needs of such a course a generalised electrical machine set has been designed in collaboration with AEI that brings into focus the underlying unity of all means for converting energy from the mechanical to the electrical form, and vice versa. 'AEI Engineering' for September contains a full description.

• The cost to the IAEA of its fellowship programme in 1960 was in excess of $1½ million, an increase of nearly $400,000 over 1959. The total number of fellowships awarded 1958-1960 was over 1000, representing 54 different countries.

• An improved galvanometer, the *Varicoil* Magnetometer, has been introduced by Griffin for advanced level physics teaching in the GCE. It enables the relationship between field and all three variables in the reduction factor to be established.

• Describing the Hayward Tyler apprentice training scheme is 'Moment of Decision' a new publication for school leavers. This is an admirable and well designed production that should be seen by other training officers contemplating a similar production.

• BEAMA have issued a third edition of 'Scholarships for training in electrical and allied engineering'. In it are lists of scholarships open to non-graduates, details of post-graduate scholarships and research awards available, and indications of the opportunities for foreign study.

UK COURSES

Battersea College of Technology, London Applied physical chemistry for metallurgists, 10 lectures Wednesday evenings commencing October 11, Fee: £1.

Borough Polytechnic, London Refractories, 10 lectures, Friday evenings commencing October 6th, Fee: £1; Metallurgy of semiconductors, 8 evening lectures commencing October 24, Fee: £1.

Bristol College of Science and Technology Introduction to nuclear power II: reactor physics, 10 weekly lectures commencing Tuesday evening January 9. Servomechanisms: 5-day courses, November 13-17.

Council of Industrial Design, London, SW1 Design appreciation courses for engineers: staff course for draughtsmen, etc., October 23-27, November 20-24, Fee: £36 15s; executives' course, November 27–December 1, Fee: £26 5s.

Hendon Technical College, Middlesex Applications of radioisotopes, 6 evening lectures commencing October 30, Fee: 10s.; Electronics for engineers, 15 evening lectures commencing October 31, Fee: 30s.

Northampton College, London Introduction to nuclear power, Thursday evenings October 12-March 22; Reactor instrumentation and measurements, Tuesday evenings October 10 to March 13, Fee for each: £4 4s.; Applied electronics, 14 evening lectures October 17 to February 20, Fee: £5 5s.; Heat transfer, 19 evening lectures commencing October 10, Fee: £6 6s.; Gas dynamics for mechanical engineers, 16 weeks course commencing October 9, Fee: £3 3s.

Royal Institution of Great Britain, London Friday evening discourses: Seeing atomic defects in metals, by P. B. Hirsch, November 24; Restless atoms in solids, by Dame K. Lonsdale, December 8.

Institution of Engineers and Shipbuilders, Glasgow Refresher course for works and plant engineers, organized by the Institution of Plant Engineers, 18 evening lectures commencing November 1, Fee: £4 4s.

Now, in ready-reference form, comes a new guide to the complete range of Mullard halogen quenched G.M. tubes. It is arranged to help you evaluate the most suitable tube for any application quickly and easily. Whether you are designing equipment or considering tubes for replacement, you'll find it saves time to have a copy at your fingertips. Send for yours today.

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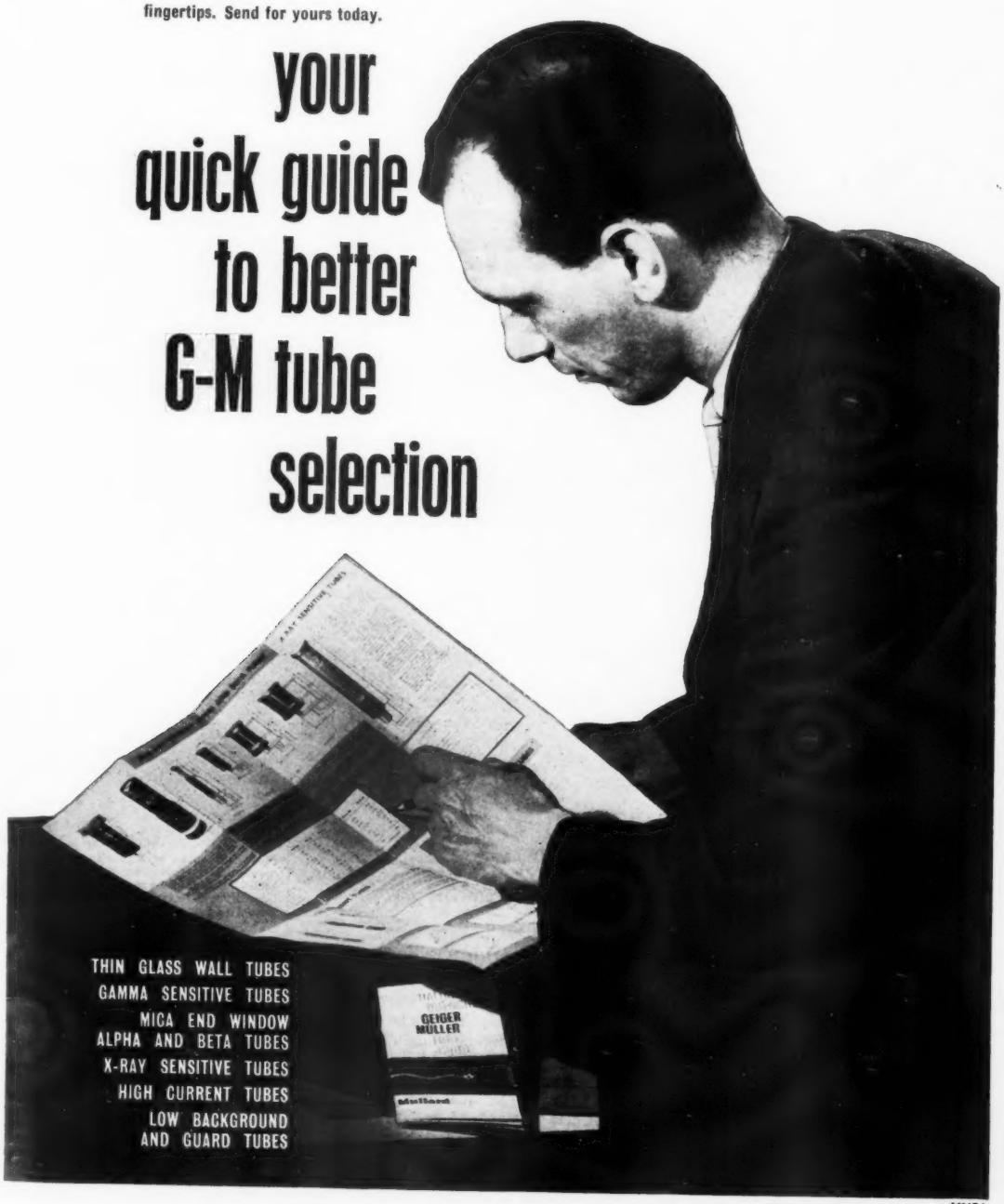


MXR1

ISOTOPE REVIEW

NEW TECHNIQUES

High intensity radiation laboratory

The design of what is described as the world's first high-intensity radiation laboratory has now been completed. Initial construction work is underway at Brookhaven National Laboratory, Long Island. According to Burns & Roe, the New York engineering and construction firm, experimental work at the laboratory is scheduled to begin in July, 1962. At the start, high intensity radiation will be provided by 500,000 curies of cobalt–60, now in storage at the site. The amount of source material will be doubled later to raise the radiation level to one million curies. Studies to be undertaken at the laboratory will include the effects of radiation on foodstuffs, packaging materials, rubber products, chemicals and others. Work will also be undertaken to find economic uses for radioactive wastes from reactor fuel elements.

Food processing research

New areas for research and development in low dose radiation processing of food include fish protein availability studies and a fruit marketing study. Some details of this work was given by Paul C. Aebersold, Director, Division of Isotopes Development, USAEC, at the Tenth Pacific Science Congress in Hawaii. Generally, he said, the US programme concentrated on two classes of foods—fish, specifically clams, haddock, shrimp, crab and flounder; and fruit. Relatively low doses of radiation were to be used to inhibit the growth of microbes during the usual conditions of distribution and storage of perishable foods. However, it was difficult to say when successful commercial processes would be made available.

Iodine-125 production

Curie quantities of iodine-125 are currently being produced at Oak Ridge National Laboratory (see *Isotope Review*, October). The new radioisotope will complement, and eventually may replace in medical investigations, the better-known iodine-131. Although the new isotope can be produced by several reactions, best results have been obtained by irradiating xenon gas in the Oak Ridge Research Reactor. Iodine-125, previously available in research quantities at $15 per millicurie, is now produced for $1 per mc on a production basis.

US plans more generators

A 25 watt generator which will be used in planned US moon landings will use curium-242 as a fuel. Mr R. Wilson, AEC Commissioner, told a recent Congressional hearing on the US nuclear rocket programme that research and development on this unit would be carried out during the 1962 fiscal year. The curium was produced by reactor irradiation of americium-241 and processes for fabrication of americium target capsules and for the production of curium had already been worked out. In addition, techniques for curium purification and encapsulation had been developed. 'The first americium target is now undergoing irradiation and processing of the curium is expected to begin on a pilot plant basis this December at the Quehanna hot-cell facilities,' Mr Wilson added.

Further work was going on to develop a demonstration thermionic unit which could be fuelled with a radioisotope. The AEC was also designing and would build, an electrically heated thermoelectric unit stimulating a generator fuelled with mixed fission products. This latter project would determine the feasibility of using mixed waste fission products as low power density heat sources.

NEWS ROUND-UP

Space generator's success

The radioisotope-powered generator in the US TRANSIT-IV-A satellite, a thermoelectric generator fuelled with plutonium-238, has produced 4601 watt hours of electrical energy in the ten weeks it has been orbiting the earth (see *Isotope Review*, August). The SNAP device (Systems for Nuclear Auxiliary Power) weighs 4·6 lbs and has already done the work of 100 times its weight in storage batteries. According to an AEC announcement, this flight test may well be the forerunner of a higher-powered operational TRANSIT power supply. The performance of the present generator is being evaluated for its possible application to this proposed operational satellite.

Japanese processing plant

A plant which will enable Japan to produce its first domestic supplies of radio-pharmaceuticals may be built soon. An application to construct the plant has been filed with the Japanese Government by Abbott Laboratories (US) subsidiary in Switzerland and the Dainippon Pharmaceutical Co. Ltd of Osaka. A new joint company would be set up to be known as Dainabot Radioisotope Laboratories Ltd. This would build a processing plant in Matsudo, a Tokyo suburb, which could be in operation by mid-1962 provided approval was granted this year.

Fission byproduct recovery

Two recent shipments of highly purified strontium-90 from the Hanford atomic plant in the US mark the beginning of a large radioisotope recovery programme being undertaken for the USAEC by US General Electric who operate the Hanford plant. The AEC is preparing to make large quantities of useful fission products available to private industry for fabrication into batteries and other devices. At present, strontium purification is being done at Hanford's high-level radiochemistry laboratory. Ion-exchange equipment designed for the experimental purification of promethium was modified for the purpose. A total of 80,000 curies of strontium are to be purified in this manner but purification will eventually be carried out at Hanford's hot semiworks.

Radiation chemistry The setting up of a central laboratory of radiation chemistry has been recommended in a recent report by the Japan Atomic Energy Research Institute. It recommends the building of a pilot plant using large radiation sources which would come into use from 1964. Other facilities would include cobalt–60 irradiation equipment, a Dynamitron (2 MeV) and a linear accelerator (12 MeV).

Exposure study A study of the radiation exposure of persons working with reactor produced radioisotopes is to be carried out by the National Sanitation Foundation, School of Public Health, University of Michigan, under a $28,000 grant from the US Atomic Energy Commission.

Irradiated foods Evaluating the wholesomeness of irradiated foods was the subject of an IAEA/World Health Organization/FAO-sponsored meeting held in Brussels from October 23–30. It dealt primarily with the nutritional value and possible toxicity of irradiated food.

Cancer treatment An extensive long range effort which will improve the benefits from radiation treatment of cancer has been announced by the US Public Health Service. It will take the form of grants to be allocated by the National Cancer Institute.

AEC affluents amendment The USAEC is proposing an amendment to its regulations which will provide additional ways to determine a permissible concentration limit for a mixture of radioisotopes contained in affluents released into air or water.

Japanese research centre The Japanese First Atomic Power Industry Group's Radiation Research Institute Inc. has completed a laboratory in Yokosuka City. Main use will be research into industrial uses of radiation and radioisotopes. Equipment includes a 12 MeV linear accelerator made by Fuji Electric and Kobe Kogyo.

Nuclear medicine Financial support for setting up an Institute of Nuclear Medicine at the Middlesex Hospital Medical School has been earmarked by the Nuffield Foundation, says the 16th annual report of the Foundation. A sum of £220,000 is to be spent on building and equipment for the application to medicine of such techniques as those involving the use of radioisotopes.

USEFUL READING

The RCL Counter, periodical review of products and developments by Radiation Counter Laboratories Inc., 5121 West Grove Street, Skokie, Illinois, USA.

New Advances in Radiation Detection, product review issued by Nuclear Measurements Corporation, 2460 N. Arlington Avenue, Indianapolis, 18, Ind., U.S.A. Export representatives, Rocke International Corporation, 13 East 40th Street, New York 16.

Decon Reference Chart (decontamination), published by Turco Products Inc., PO Box 1055 Wilmington California. Also available from Turco Chemical Products Ltd, Victoria Road, Southborough, Kent, England.

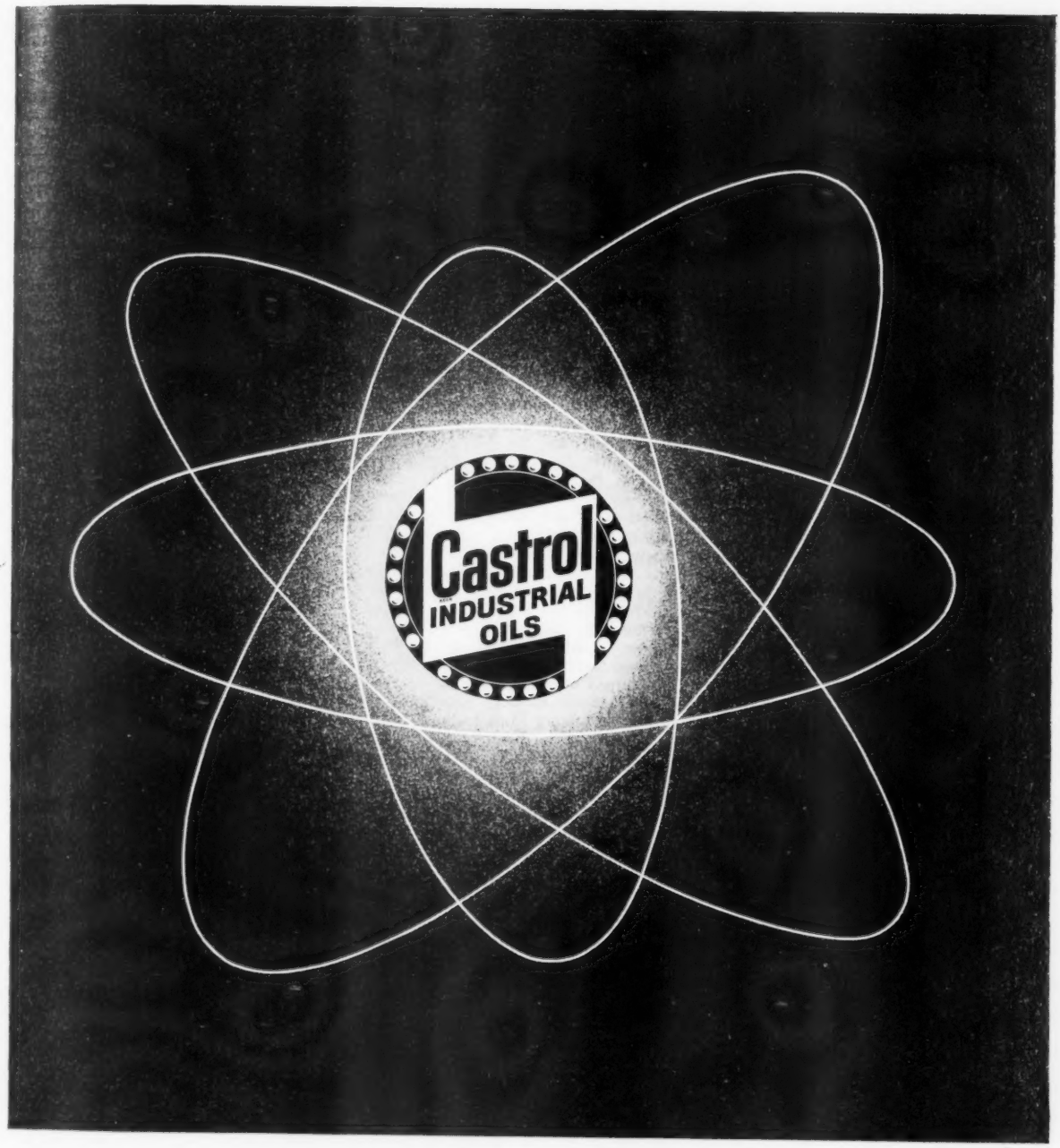
Nuclear Catalogue, Ray Proof Corporation, 843 Canal Street, Stamford, Conn.,

Hand and Foot Monitor, Eberline Instrument Corporation, PO Box 279, Santa Fe, New Mexico.

Radiation Protection Guide (chart), Nucleonic Corporation of America, 196 Degraw Street, Brooklyn 31, New York, USA.

Gamma Radiography, Pantatron Ltd, 5a Princes Street, Hanover Square, London W1.

Electronic control safeguards patient in radiation therapy—a description of the cobalt therapy unit at St Thomas's Hospital, London, in the April-May issue of the MI Review, published by the Metal Industries Group, Park Lane, London W1.



NUCLEOL

RADIATION RESISTANT LUBRICANTS

chosen for Chapelcross, Berkeley and Dungeness

Castrol Industrial Ltd., Castrol House, Marylebone Road, London, N.W.1. A member of the Castrol Group of Companies

Book Reviews

Nuclear accountancy in US installations

Management, in this book, means material control and accounting. This topic is treated in seven main sections dealing with management considerations, raw materials, feed materials processing, reactor fuel fabrication, reactor operation, scrap and irradiated material processing, and research and development facilities. Each section is sub-divided into chapters contributed by one or more specialist authors.

The various chapters are self-contained, which on a through-reading of the text of about 500 pages, gives the impression of extreme repetition, although individually the chapters are clearly written. In each, an account is given of the process flowsheets under consideration, the type of plant and operation involved and the methods of sampling, measurement and data collection. The statistical basis of the accounting process is treated, in some chapters at length, and the inventory and technical records procedures are explained with specimen forms.

In its stated objective, the book is of value to a very restricted field of readers. Much of the detail would only be of interest to those directly concerned with nuclear materials' accountancy, for whom the real problem is the assessment of the return which can be obtained for a given investment in accounting cost. This problem is mentioned in the first section but receives no quantitative treatment later in the book. It is therefore difficult to assess the relevance of much of the detail to nuclear installations other than those operated for the US AEC.

The general reader will find, within the limits imposed by security restrictions, an account with flowsheets and photographs, of all the main processes involved in nuclear technology, together with the methods of process control and an indication of analytical procedures. The cost of the book is such that its purchase for this purpose alone would be difficult to justify.

N. L. Franklin

Management of nuclear materials by R. F. Lumb. Van Nostrand, New York and London, 1960. 560 pp. Price 124s.

Versatile technique for analysts

The twelve papers presented at the five sessions of this IAEA symposium were given by international experts, and covered a wide variety of applications. G. B. Cook reviewed the basic principles of radioactivation analysis, with particular reference to sources of error. This is followed by K. Ljunggren describing a triple coincidence spectrometer. The first paper on applications is that by W. Herr, describing in considerable detail the application of neutron activation to geochemistry. He demonstrates the value of this tool in geological dating, quoting a large and impressive number of results. P. Leveque discusses the possibilities of analytical methods depending on the excitation of radiation following interaction, citing the use of k-X rays from Fe-55 for sulphur determination, moisture determination using neutron moderation, selective absorption for C/H ratio, and X-ray fluorescent spectrometry. G. W. Leddicote's paper continues the theme of G. B. Cook's review and gives a wealth of detail about work in the USA in many fields of investigation. There is a useful collection of 83 references. In a more closely defined field, J. M. A. Lenihan discusses a large variety of examples of the use of radioactivation analysis in biochemistry and medicine, reporting the results of many analyses, including a study of the levels of arsenic found in body and other tissues.

Concerned with metallurgical applications is J. Hoste who deals with the determination of minor constituents in high alloy steels, in particular vanadium and tungsten, comparing the method with classical analyses. Another paper, by Ph. Albert, deals with the analysis of small amounts of impurities in high purity aluminium and iron, outlining the chemical steps, and discussing the sensitivity which can be achieved.

G. Leliart's paper concerned with the solid state, deals with the distribution of mercury in quartz, and with the diffusion of arsenic and phosphorus in germanium. Three papers deal with single problems: the Detection of mercury, mainly in biological samples, by K. Ljunggren and T. Westermark; the Determination of tantalum in high-tantalum alloys—an example of radioactivation analysis replacing a difficult chemical analysis—by D. Gibbons and H. Simpson; and Intermetallic diffusion in gold-lead systems, by A. Ascoli and E. Germagnoli.

The book is full of information for analysts, but it should have a wider appeal by giving in a small compass a good account of a versatile technique whose applications cover almost every branch of scientific research and technology.

R. A. Faires

Radioactivation analysis Proceedings of an IAEA Symposium, Vienna, June, 1959, edited by B. R. Payne. Butterworths, London, 1960. 141 pp. Price 30s.

Misuse of materials data sheets possible

Based on articles originally published in 'Nuclear Engineering' in 1957-58, this new book covers, uranium, plutonium, thorium, ceramic fuels, graphite, magnesium, beryllium and zirconium. Each chapter has a logical description of the important properties and an appendix giving values in tabular form, an arrangement that the nuclear materials expert will find helpful. He has an inherent objection to data sheets, however, as they can be misused by engineers. The diligent engineer who reads the whole chapter will learn all the difficulties but the less careful engineer may, for example, accept the values of thermal conductivity of graphite given in the appendix without reading about the effects of irradiation on this property. This is not a criticism of the book as it is inherent in the use of data sheets, but one would have preferred 'Materials for nuclear reactors' as the title.

The preface indicates that the chapters have been brought up-to-date and there is plentiful evidence of this. There are three notable gaps, however. That there is no mention of irradiation creep in graphite, of irradiation induced gas bubbles in beryllium or of embrittlement in zirconium resulting from hydrogen pick-up in aqueous corrosion, suggests a long period in publication.

G. E. Darwin

Materials for nuclear engineers edited by A. B. McIntosh and T. J. Heal. Temple Press, London, December 1960. 384 pp. Price 75s.

New books

• *Advances in electron tube techniques:* proceedings of the Fifth National Conference, September 1960, edited by D. Slater Pergamon, Oxford and London, 1961 235 pp Price £5

★ 262

• *Encyclopaedic dictionary of physics* edited by J. Thewlis *et al* Volume 1: A to Co Pergamon, Oxford and London, 1961 800 pp Price £100 per set

★ 263

• *Modern atomic and nuclear physics* by C. S. Cook Van Nostrand, New York and London, 1961 296 pp Price 58s 6d

★ 264

• *Radiation Damage in solids* by D. S. Billington and J. H. Crawford, Jr Princeton University Press and OUP, London, 1961 450 pp Price 75s

★ 265

• *Theory of direct nuclear reactions* by W. Tobocman Oxford University Press, 1961 104 pp Price 15s

★ 266

• *Fuel element fabrication*; with special emphasis on cladding materials: proceedings of a Symposium held in Vienna, May 1960, volume 1 Academic Press, London and New York, 1961 538 pp Price £5

★ 267

• *Nuclear pulse spectrometry* by R. L. Chase McGraw-Hill, New York and London, 1961 221 pp Price 66s

★ 268

• *British miniature electronic components and assemblies data annual* 1961-62 edited by G. W. A. Dummer and J. M. Robertson Pergamon, Oxford and London, 1961 479 pp Price £4

★ 269

★ *For further information on any item, circle the appropriate number on the reply card facing page* 106.

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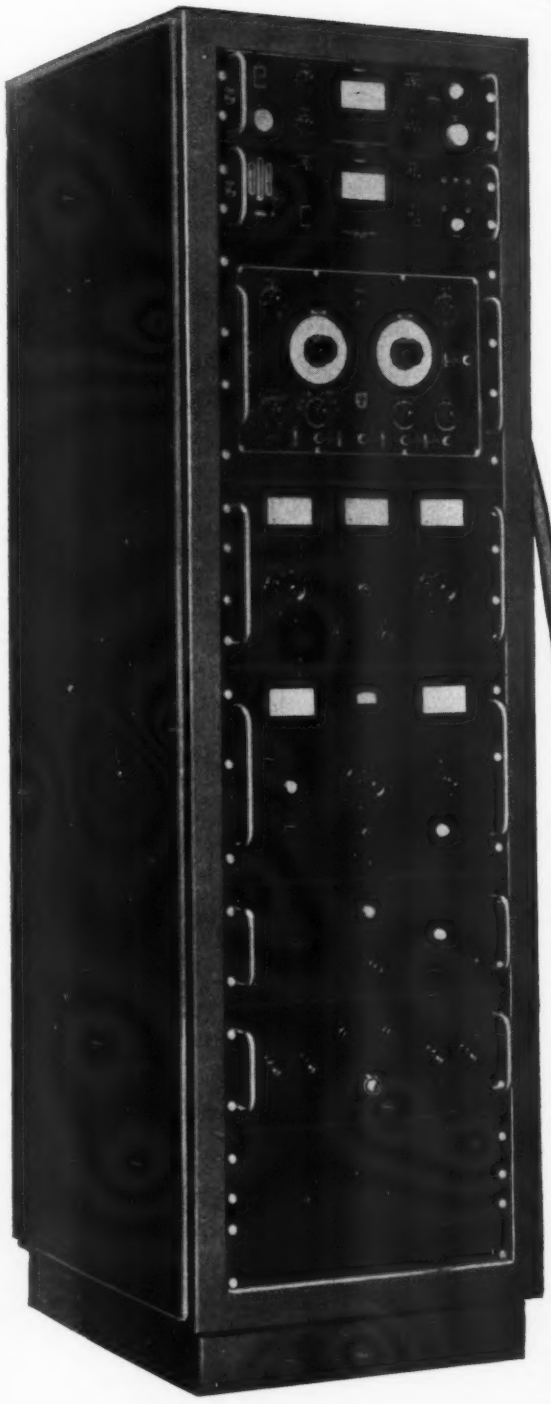

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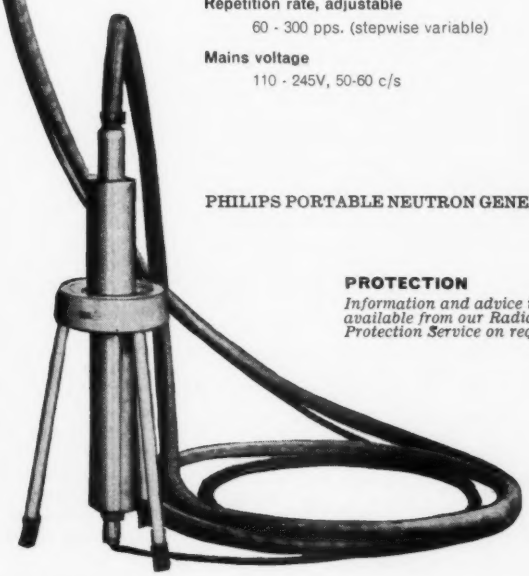

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People

by John Radford

T. P. HUGHES
joins 'Bostick'

A SHORT TOUR of reactor operations centres in the UK and Western Europe was recently carried out by **G. A. Tingate,** Reactor Operations Engineer with the Australian Atomic Energy Commission. He is in charge of all reactors operated by the AAEC. During his visit, Mr Tingate had discussions with reactor engineers at Oslo, Riso, Julich, Saclay, the AEA and toured various industrial firms in the UK.

Two other Australians, **Kenneth P. Nicholson** and **J. E. Hayes** have arrived in the UK for long term attachments. Mr Nicholson will carry out a two year spell of duty with the AEA when he will undertake research into advanced reactor physics at Harwell in the division led by **Dr Bretscher.** Mr Hayes, who is a research officer, will first go to Harwell for the Reactor School course and then go on to Risley where he will be engaged on engineering research and development work related to nuclear power stations.

The new general manager of Head Wrightson Stockton Ltd is **Mr J. D. Eccles,** son of **Sir David Eccles,** Minister of Education. Mr Eccles, who is also a director, joined Head Wrightson Steel Foundries Ltd and then became manager of the Stockton steel plant, later becoming a director. Other appointments announced by Head Wrightson include that of **G. F. Taylor** as general manager of Head Wrightson Steel Foundries Ltd and **A. J. Long** who has joined The Head Wrightson Export Company as general manager.

Joining B. B. Chemical Co Ltd from Tube Investments Ltd where he was TI's first Director of Research, is **Dr T. P. Hughes.** He becomes joint assistant managing director of BB Chemical (Bostik). Aged 46, Dr Hughes was with the Ministry of Supply before joining TI and from 1940-47 was with the Shell Petroleum Co as chief chemist at their aero engine laboratory.

In brief

Mansfield D. Sprague, vice-president and director of the American Machine & Foundry Company, has been elected president and chief executive officer of AMF Overseas Corporation, Geneva.

Ultra Electronics announce that **Dr F. W. Stoneman** is now executive director, sales and engineering and **Allan Sadler** is now chief engineer.

Dr D. H. Sharp has been appointed director (Technical) of the Federation of British Industries as from November 1, 1961. He succeeds Major-General **A. J. H. Dove** who is leaving the FBI at his own request.

Dr Peter Mathijsen, a member of the legal department of Euratom, will study and lecture at the University of Michigan Law School this autumn.

W. L. Fairless is the manager of Atlas Copco's new international technical advice bureau in London.

C. R. Russell, manager, export sales, M-O Valve Co. Ltd, has been appointed Product Planning Adviser to the management of the company.

Gerald L. Phillippe has been elected president of US General Electric and **C. W. LaPierre** executive vice-president.

BUSINESS NEWS

EURATOM REACTOR AWARD The Dutch **Neratoom** Group has been awarded a contract to build a reactor at Ispra for Euratom. The reactor, a critical experiment, will be known as the ECO-project. This summer, the design of the reactor was completed by Neratoom (see *Worldview*, August p 53) in co-operation with **RCN** and the engineering companies, **Comrimo** and **Tebodin**. In accepting the order for the design of the project, Neratoom and other industrial groups in the Euratom countries pledged themselves to carry out their particular design if it should be accepted. Delivery of the reactor will take place in 1963.

GE's FUEL ORDER A fuel element contract worth $124,000 has been awarded to the US **General Electric** by Cornell University. It is for 915 fuel elements and 1650 uranium-dioxide fuel pellets for the zero power reactor at the university. A feature of the contract is that 100 of the fuel elements to be supplied will be empty and will have removable ends. Fifteen control elements partly filled with uranium dioxide fuel and partly with a boron compound will also be provided.

AEA COMPUTER CONTRACT The **UKAEA** has signed a contract with **IBM** for a STRETCH computer which will be installed in 1962. The order was placed last year. This brings to four, the number of IBM computers the AEA will have in use. The latest machine will be installed at Aldermaston. The other computers, a 704, 709 and 7090, are installed at Aldermaston and Risley. Last month, the AEA reached an agreement for the purchase of an Atlas computer (see *Business News*, September). It was also announced later that the **Plessey Company** had received a contract for some £450,000 for ferrite core memory systems for the Atlas computer.

JOINT REACTOR USE Five industrial organizations and two other universities have made use of the 1 MW Ford Nuclear Reactor at the University of Michigan during the past year. The number of experiment hours these groups used the reactor varied from a high of 3447 hours by **Bendix Systems Division** to two seconds by **General Motors Research Institute.** Other industrial organizations using the reactor in the year to June 30 were **Consumers Power Company, Anaconda Copper** and the **Ford Scientific Laboratory.**

• Nearly £40,000 worth of hand and clothing monitors and portable contamination monitors have been installed at Berkeley nuclear power station by **EMI Electronics Ltd.** The CEGB has also placed a contract for over £40,000 with EMI Electronics for hand and clothing monitors, single hand monitors and portable monitors for use at Hinkley Point nuclear power station.

• The **USAEC** has signed its first contract making financial arrangements for the processing or irradiated reactor fuel returned from a licensed firm. Fuel elements used in the original core of the **US General Electric**'s Vallecitos BWR will be accepted by the AEC at its National Reactor Testing Station, Idaho.

• A Ministry of Aviation contract to supply a further quantity of radiac survey meters has been awarded to **Avo,** a company in the Metal Industries Group.

• **George Kent Ltd** of Luton have received an order for instrumentation worth more than £32,000 for Trawsfynydd nuclear power station. The order takes in all reactor control room instrumentation.

• The German-American firm, **Interatom,** has bought a Pace analogue computing system costing almost £50,000.

• **Tracerlab** has received its largest single order for a reactor monitoring system. The US firm announced that a $90,000 order was received from the AEC for designing and making a 100 channel area monitoring radiation system for the New Production Reactor under construction at Hanford, Washington.

• The **British Aluminium Co. Ltd** has purchased the 40% shareholding of **The Distillers Company Ltd** in **Magnesium Elektron Ltd.** This makes the company a fully-owned subsidiary of British Aluminium.

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Diary

30 OCTOBER–3 NOVEMBER
Welding in shipbuilding, symposium, London. Details, Institute of Marine Engineers, 76 Mark Lane, London, EC3

31 OCTOBER
Ion exchange in the atomic industry, South Wales Institute of Engineers, Park Place, Cardiff, 7.15 pm

31 OCTOBER–3 NOVEMBER
Effluent and water treatment Exhibition, Seymour Hall, London

2 NOVEMBER
Electron spin resonance, Queen Mary College, London, 2 pm. Details, The Chemical Society

7–8 NOVEMBER
Sixth BEAMA Publicity Conference, Connaught Rooms, Great Queen Street, WC2

8 NOVEMBER
Shrinkage and creep in concrete, Royal Society of Arts, John Adam Street, London, WC2, 6 pm. Organized by The Reinforced Concrete Association, 94–98 Petty France, London, SW1

8–10 NOVEMBER
Conference, **non-destructive testing in electrical engineering,** London. Details, The Institute of Electrical Engineers, Savoy Place, London, WC2

13–16 NOVEMBER
First National Maintenance Conference and Exhibition, Central Hall, London, SW1

17–18 NOVEMBER
Imperfections in crystals, London. Autumn conference, X-Ray analysis group, Institute of Physics and the Physical Society

21 NOVEMBER
The main building for the 7 GeV proton synchrotron at Harwell, London. Meeting, Institution of Civil Engineers, Great George Street, London, SW1

27–30 NOVEMBER
Corrosion and Metal Finishing Exhibition, Olympia, London

28 NOVEMBER
High temperature gas cooled reactors for marine propulsion, R. E. E. Richards, London, Institute of Marine Engineers, 5.30 pm.

30 NOVEMBER–1 DECEMBER
Nuclear electronics, symposium, London. Details, The Institution of Electrical Engineers, Savoy Place, London, WC2

OVERSEAS

23–30 OCTOBER
Technical meeting on the control of wholesomeness of **irradiated foods,** Brussels. Organized by the IAEA, World Health Organization and FAO

1–4 NOVEMBER
International conference on **high magnetic fields,** Cambridge, Massachusetts. Details, H. H. Kolm, National Magnet Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

3 NOVEMBER
Conference on **radioisotopes—New Horizons in Mineral Industries,** Pittsburgh, USA. Sponsored by Pittsburgh section, American Institute of Metallurgical Engineers with the co-operation of the AEC's Division of Isotopes. Details, R. G. Redelfs, chairman, Mineral Industries Group, St. Joseph Lead Co, Zinc Smelting Division, Monaca 7, Pa., USA

6–9 NOVEMBER
Annual meeting, Atomic Industrial Forum and winter meeting of the American Nuclear Society, including 9th **Hot Laboratories and Equipment Conference and Atom Fair,** Chicago, Illinois

6–10 NOVEMBER
Regional seminar on **educational problems of nuclear energy,** San Carlos de Bariloche, Argentina. Organized by the IAEA in co-operation with the Inter-American Nuclear Energy Agency

7–12 NOVEMBER
Sixth Conference and Exhibition of automation and instrumentation, including items on nuclear physics, Milan, Italy. Details, Federazione delle Societa scientifiche e techniche di Milano, Via S. Tomaso 3, Milan, Italy

9–11 NOVEMBER
1961 **National Youth Conference on the Atom,** Chicago. Details, Bozell & Jacobs Inc., 230 Park Avenue, New York 17, USA

14–15 NOVEMBER
Conference on **radioisotopes—New Tools for Industry,** Boston, USA. Details, Raymond I. Rigney, Co-ordinator, The Commonwealth of Massachusetts Commission on Atomic Energy, 150 Causeway Street, Boston 14, Massachusetts, USA

15–18 NOVEMBER
Third annual meeting of the division of plasma physics of the American Physical Society, Colorado Springs, USA

21 NOVEMBER–1 DECEMBER
Use of radioisotopes in animal biology and the medical sciences, Mexico City. Organized by the IAEA, World Health Organization and FAO

—1962—

8–12 JANUARY
International **Heat transfer** conference, London. Details, Institution of Mechanical Engineers, 1 Birdcage Walk, London, SW1

5–9 NOVEMBER
Third World **Metallurgical Congress,** Chicago. Details, Exposition Manager, American Society for Metals, 7301 Euclid Avenue, Cleveland 3

Industrial Literature

Metals research. Böhler of Vienna have available a folder containing a selection of technical and scientific articles describing their work on steels for high temperature use and the development of other materials for use under corrosion conditions.

★ **247**

Gas analysis. The Mono range of electrically driven automatic recording gas analysers, covered in a recent leaflet from Gordon's, caters for two or three gas constituents.

★ **248**

Beryllium oxide. Typical values for the electrical, thermal and physical properties of two UOX BeO bodies are provided in new data sheets from Brush Beryllium.

★ **249**

Ball valves. A recent leaflet from Hindle covers the new B15 fluon seated leakproof ball valve. These are available in sizes 2 in to 16 in and are interchangeable with standard valves.

★ **250**

Wiring connexions. Based on solderless crimped cable connexions, the Crabtree wiring system seems to be well suited for use in electronic instrumentation, according to C.W.C. Equipment, who are supplying the UKAEA with large numbers of the latest cable ferrules, blocks, etc. Two leaflets are available describing the system.

★ **251**

Boiler water analysis. Cambridge Instrument's list 323/3 gives details of their electrochemical dissolved oxygen analyser Mark IV. Completely specific analysis of dissolved oxygen content down to 1g in 2000 million g of water are given. Another leaflet, no. 103, describes an indicating pneumatic controller for controlling working temperatures between 20°C and 340°C.

★ **252**

Rotoplunge pumps. Parkinson Cowan's latest brochure covers the features of their range of Rotoplunge pumps that have only three moving parts and cater for outputs from 7·5 gal/h to 2300 gal/h. The working principle is that of a plunger, housed in a cylinder which is radially situated in a rotor.

★ **253**

Electronic cabinets. The basic range of cabinets and consoles available from Hassett & Harper, together with examples of custom built assemblies, are illustrated in a recent catalogue.

★ **254**

Solid state devices. International Rectifier's new short form catalogue includes a new miniature 200 mA glass diode, the 5A series of encapsulated diffused rectifiers rated at 1 A and the X10B series of diffused rectifiers rated at 1·3 A. For accurate and temperature stable reference voltage is the new 1N429 reference element capable of handling 200 mW.

★ **255**

Mass spectrometer. A new bulletin from Consolidated Electrodynamics describes the capabilities of their type 21-130 laboratory mass spectrometer utilizing a cycloid tube with 1·1 in focal distance and a permanent magnet with a field of ≃ 4500 gauss. Unit resolution is attained at mass 200 with usable resolution to at least mass 230.

★ **256**

Transformer oil. A second edition of Castrol's 'Transformer and switch oils' is now available. It deals with properties, causes of oil deterioration, the care of transformer oil and oil purification.

★ **257**

Temperature measurement. Cambridge Instrument's publication 325 describes their standard range of rare- and base-metal thermocouples suitable for temperatures up to 1500°C. The elements used are iron/constantan, nickel-chromium/nickel-aluminium, or platinum/13% rhodium-platinum.

★ **258**

Heat transfer. The properties and characteristics of ICI's heat transfer medium 'Thermex,' a eutectic mixture of diphenyl oxide and diphenyl, are covered in a recent publication.

★ **259**

Analogue computers. The value of computers for solving reactor problems and helping in turbo-generator design is emphasized in the latest issue of 'Parsons Journal' that carries an article discussing the basic operation of analogue computers.

★ **260**

Electron beam technology. The current issue of the Carl Zeiss works magazine comments on the use of the electron beam as a tool for varying industrial application, beam milling and welding in particular.

★ **261**

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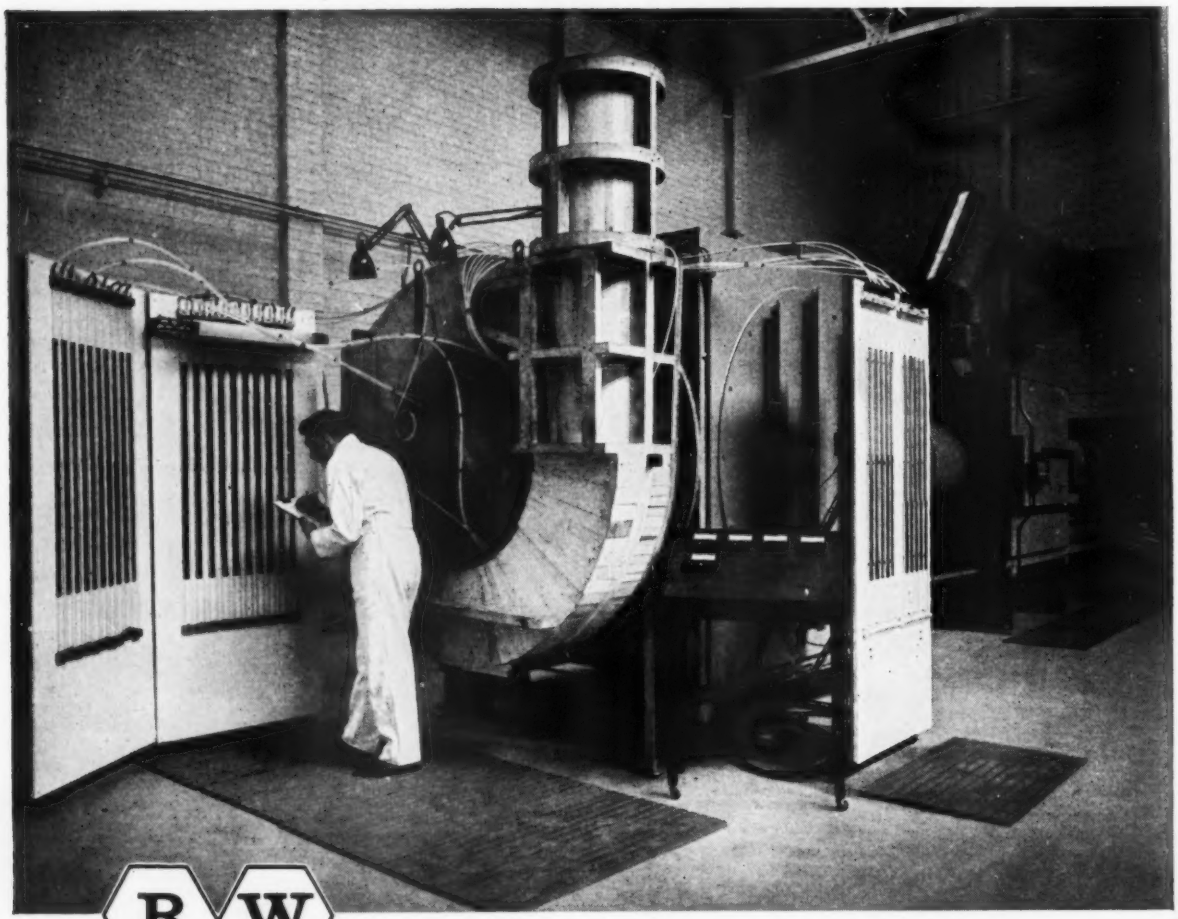

In the Aerodynamics Laboratory of the Richardsons Westgarth Group, an engineer tests an air flow model of the outlet diffuser and volute assembly for a high-speed centrifugal compressor. These volutes and diffusers will be used on a number of gas turbo-compressors at present being manufactured for a well-known Oil Company.

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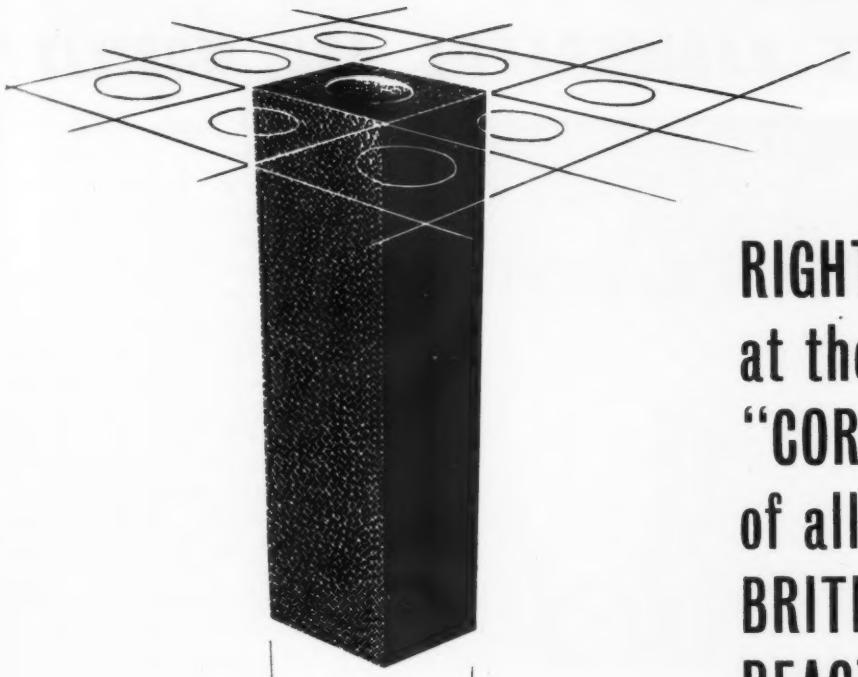

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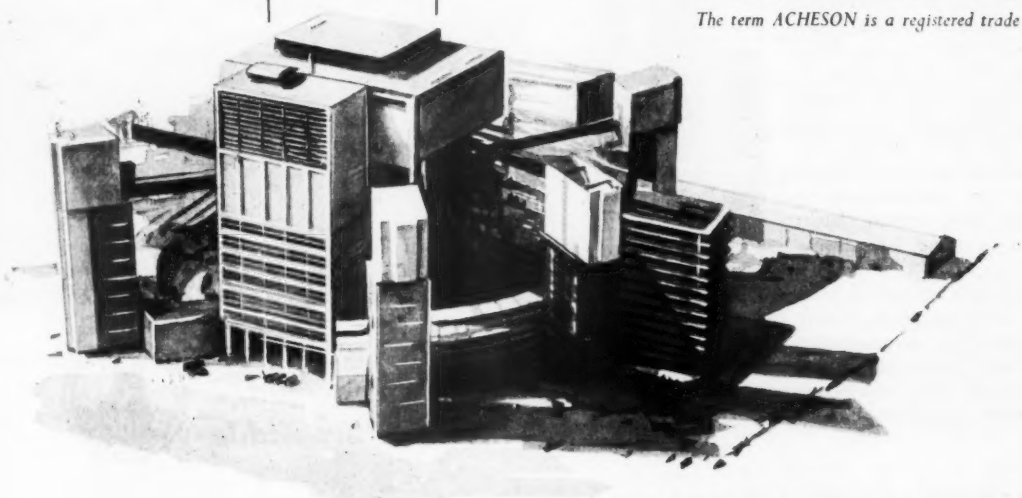

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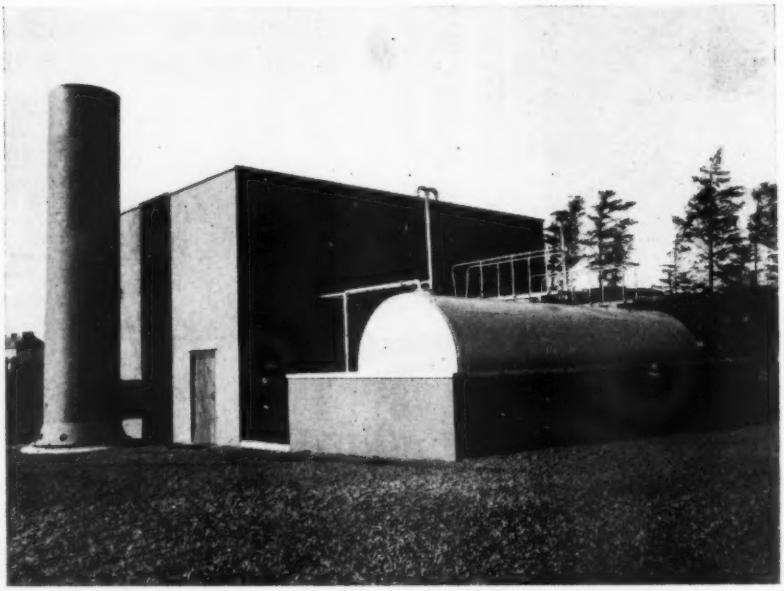

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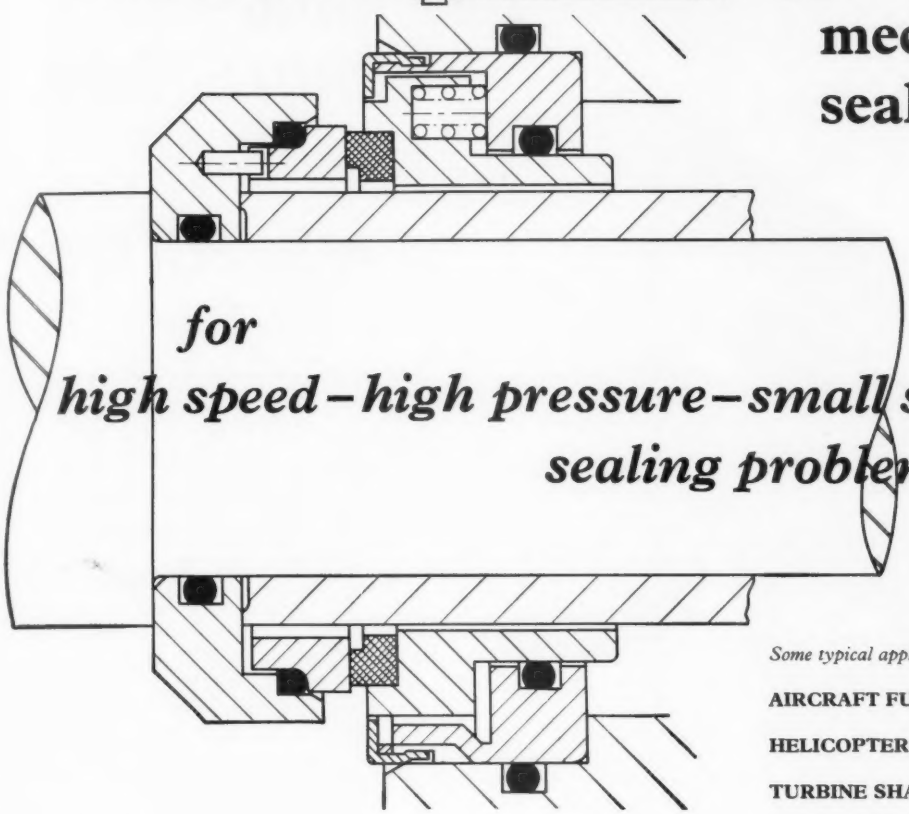

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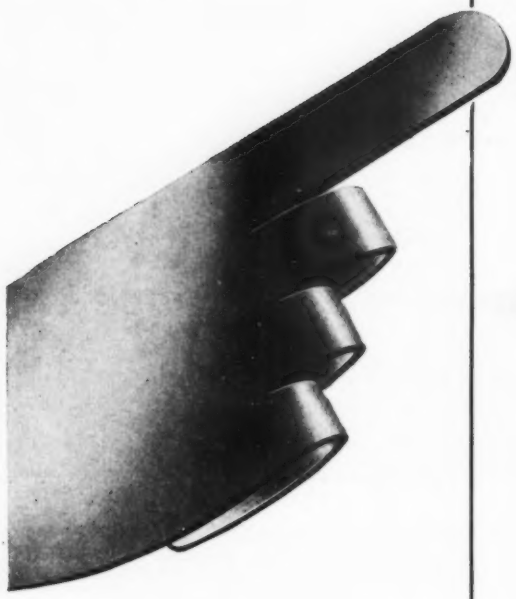

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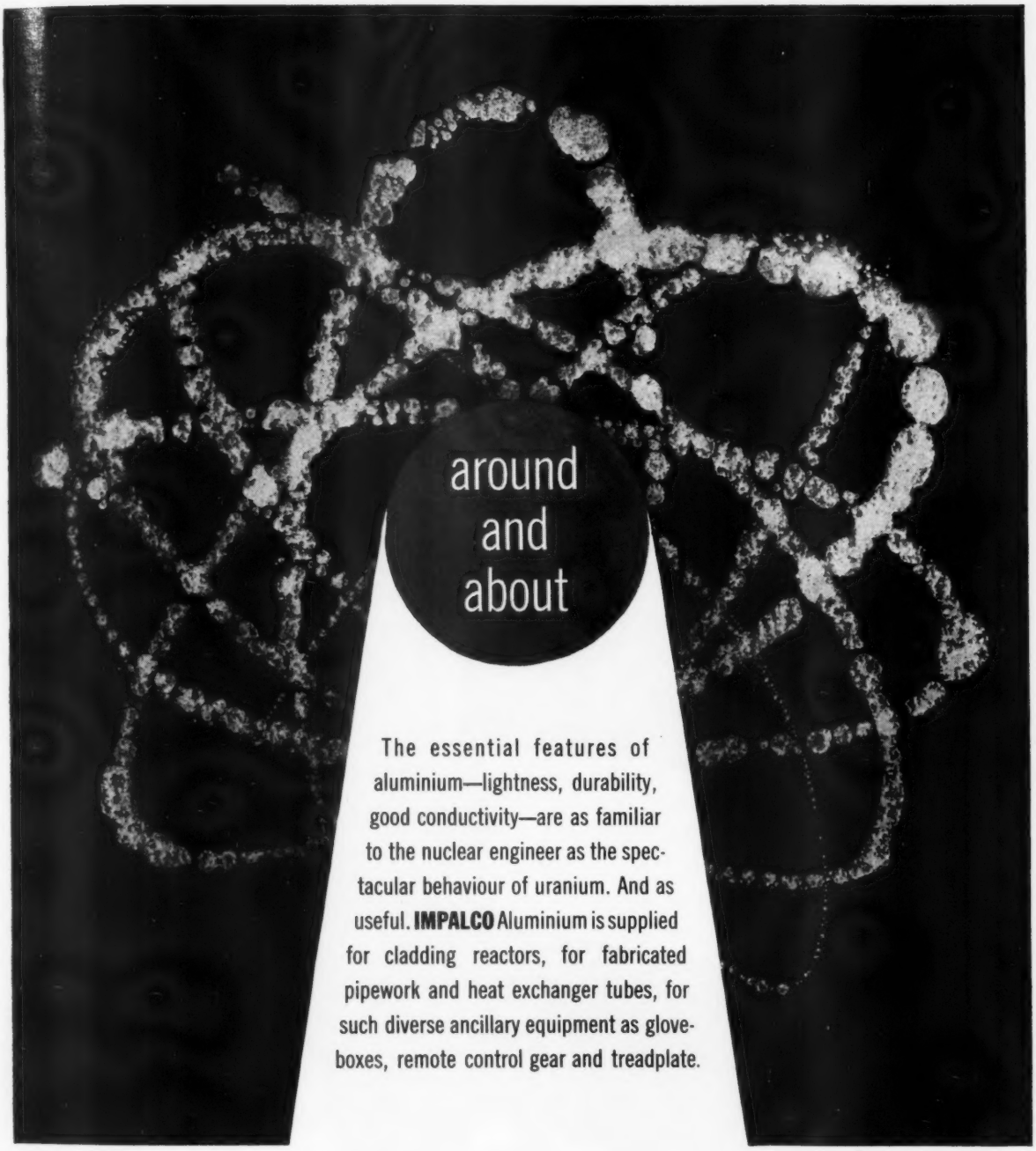

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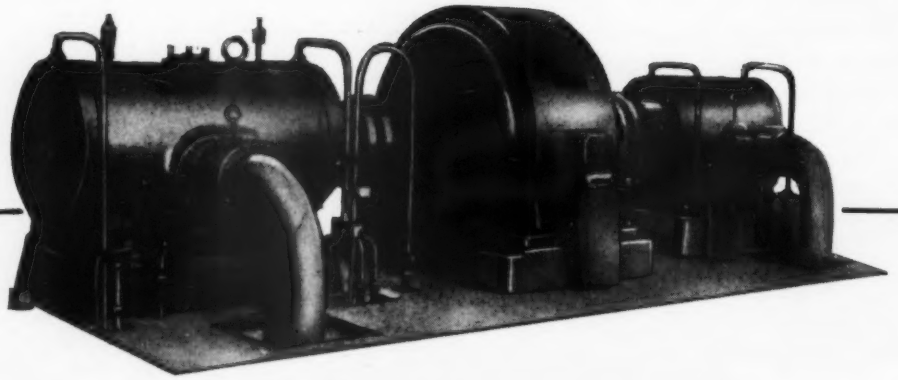

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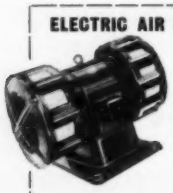

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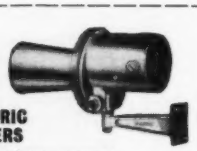

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15	38	61	84	107	130	153	176	199
16	39	62	85	108	131	154	177	200
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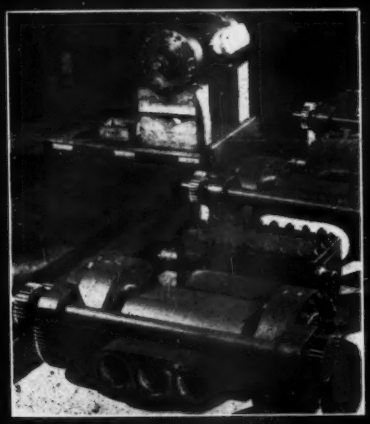

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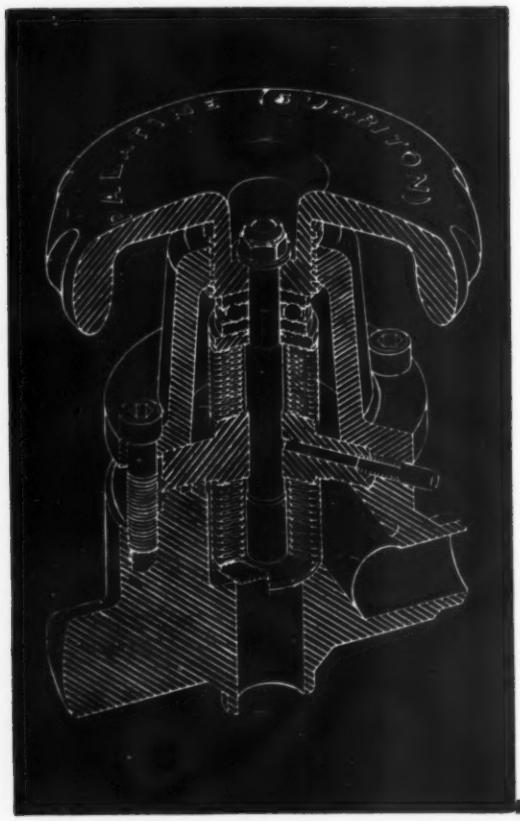

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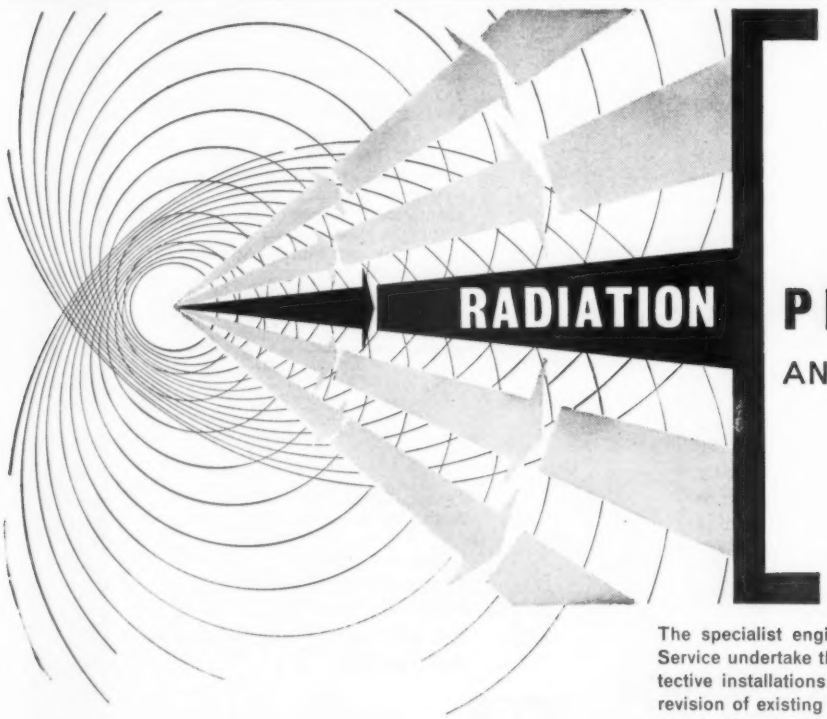

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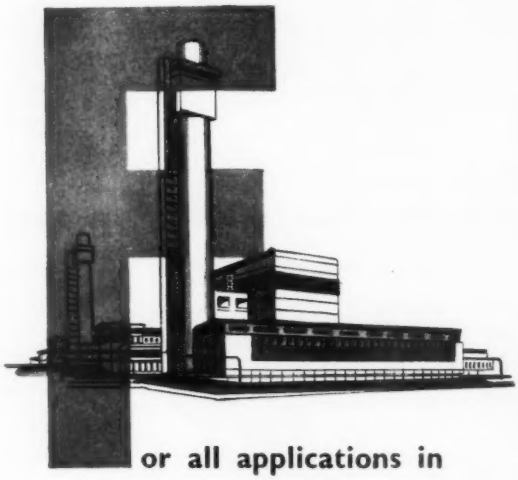

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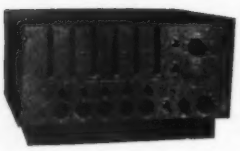

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The MAGNETEL

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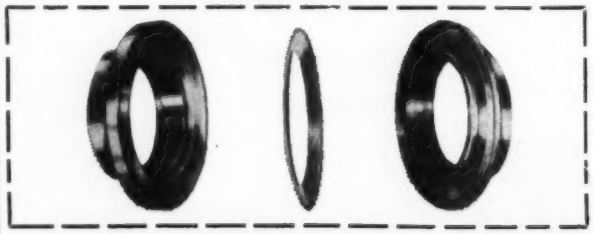

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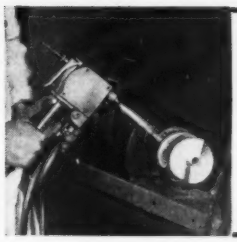

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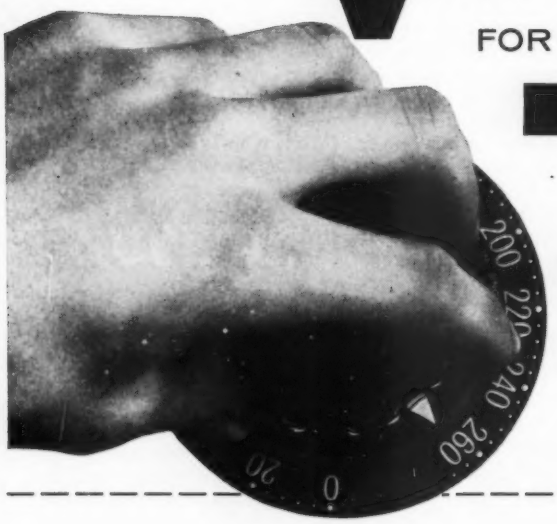

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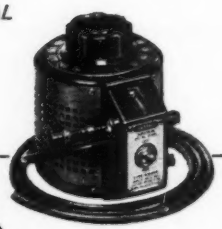

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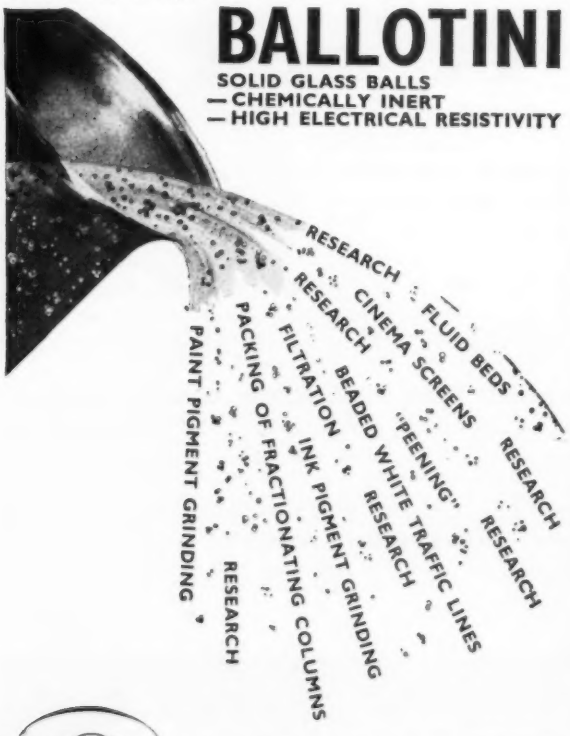

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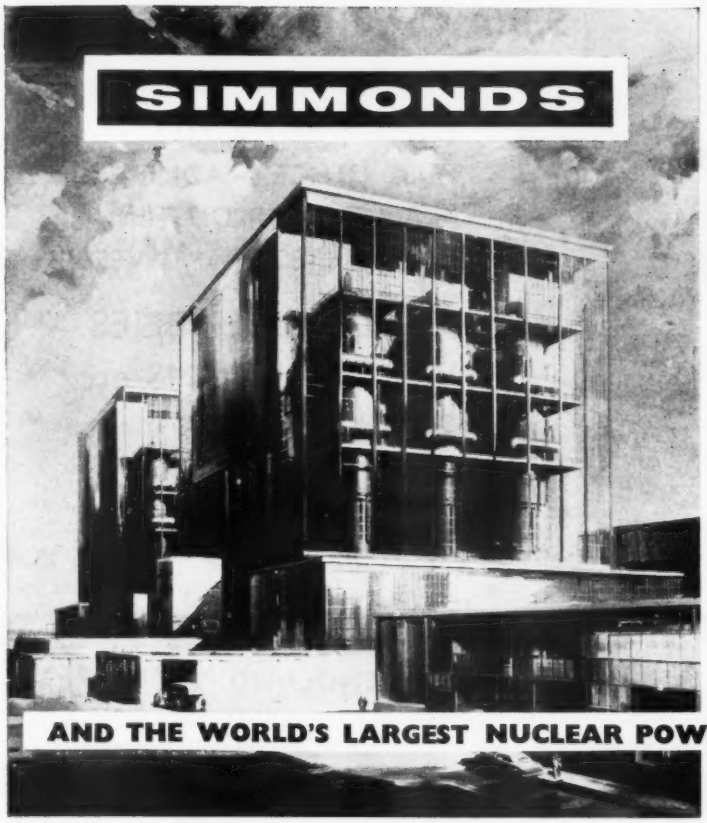

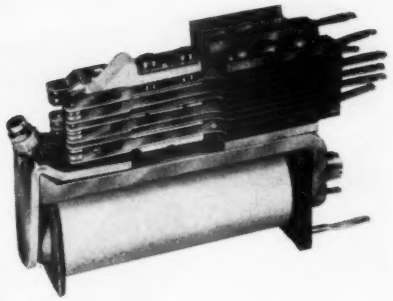

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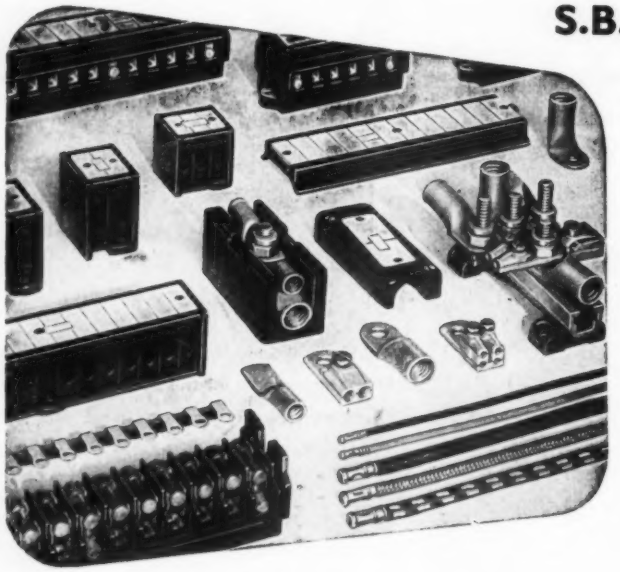

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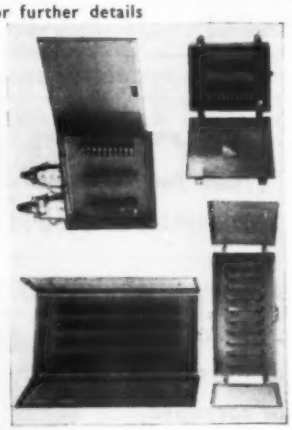

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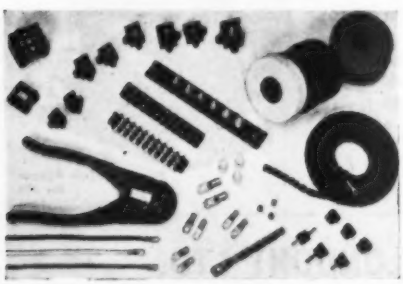

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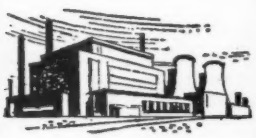

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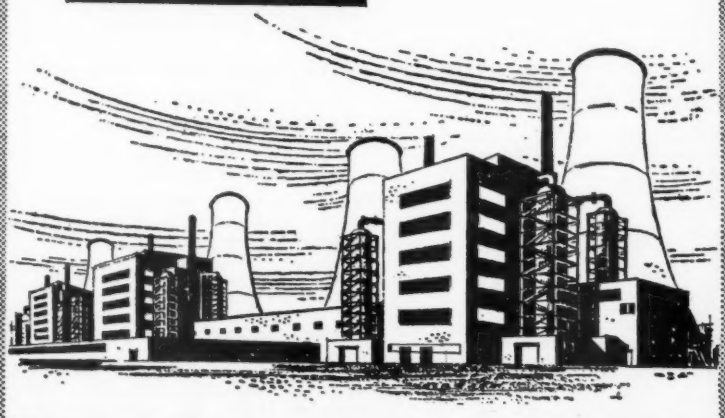

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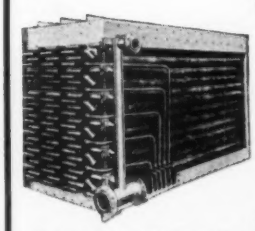

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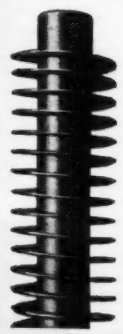

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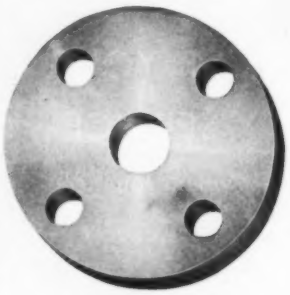

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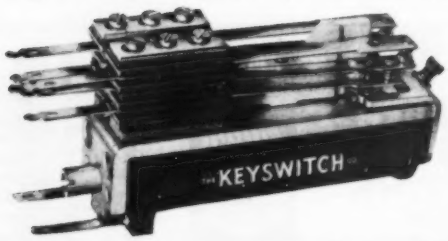

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